Fishery Data Series No. 04-02

Evaluation of Rainbow Trout in Quartz Lake, 2001 & 2002

by
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and

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March 2004

Alaska Department of Fish and Game Division of Sport Fish

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used in Division of Sport Fish Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications without definition.

Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
And	&
At	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
Trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_{2,}$ etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

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Development and publication of this manuscript were partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-17 & 18, Job No. E-3-1.

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This document should be cited as:
Fish, J. T. and C. Skaugstad. 2004. Evaluation of rainbow trout in Quartz Lake, 2001 & 2002. Alaska Department of Fish and Game, Fishery Data Series No. 04-02, Anchorage.

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ABSTRACT

In 2001, a two-sample mark-recapture experiment was conducted at Quartz Lake to estimate the abundance and size structure of age-1 rainbow trout that were stocked as young-of-the-year in late summer 2000. The estimated abundance of these trout was 1,588 fish (SE = 180), ranged in size from 55 to 170 mm FL, and averaged 111 mm FL. The overwinter survival of these fingerlings from 2000 to 2001 was less than 1%. Predation and inadequate growth after stocking in late summer are likely reasons for poor fingerling survival. Coho salmon >200 mm FL handled during mark-recapture studies ranged in size from 200 to 330 mm FL, and averaged 276 mm FL.

In 2002 a two-sample mark-recapture experiment was conducted at Quartz Lake to estimate the abundance of age-2 and older stocked rainbow trout in Quartz Lake. The estimated abundance of age-2 and older rainbow trout (≥ 200 mm FL) was 9,383 fish (SE = 2,874). An estimated 202 (SE = 91) of these fish were stocked as age-1 catchables during 2001. This represents 2% of age-1 catchables stocked during 2001. The remaining 98% of the rainbow trout stocked during 2001 were presumably harvested during 2001 and 2002. Stocking subcatchable rainbow trout into Quartz Lake during late spring/early summer is recommended to eventually sustain the fishery.

Key words: Quartz Lake, rainbow trout, *Oncorhynchus mykiss*, coho salmon, *Oncorhynchus kisutch*, age-1, age-2, juvenile, fingerlings, subcatchables, catchables, stocking evaluation, stock assessment, stocking method, length-at-age, mark-recapture, harvest.

INTRODUCTION

The Alaska Department of Fish and Game (ADF&G) stocks game fish in numerous lakes and one stream in the Tanana River valley within Alaska's interior (Figure 1). The goal is to provide diverse and dependable angling opportunities near population centers and offer alternatives to the harvest of wild fish stocks. The stocking program began in the early 1950s, when lakes along the road system were stocked with rainbow trout *Oncorhynchus mykiss*, or coho salmon *O. kisutch*. Today, the stocking program provides dependable year-round sport fishing opportunity for rainbow trout, coho salmon, chinook salmon *O. tshawytscha*, Arctic grayling *Thymallus arcticus*, and Arctic char *Salvelinus alpinus*.

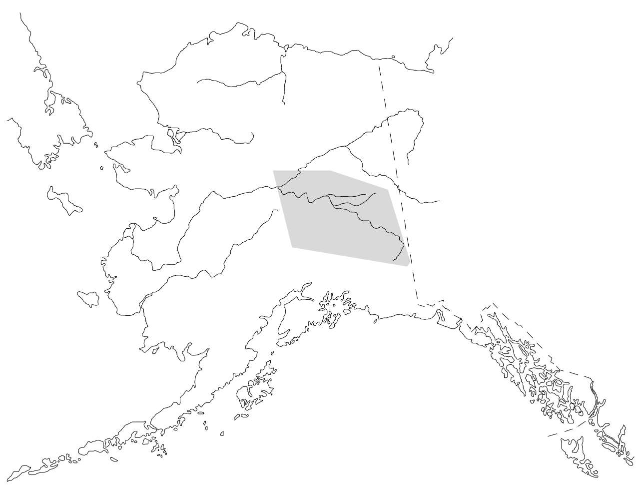

Figure 1.-The Tanana Valley (shaded area).

The stocking program supports consumptive fisheries along the road system where fishing effort and harvests are greatest. As a conservation tool, it serves to divert harvest away from wild populations that cannot support high levels of consumptive use desired by anglers. Anglers and businesses in the Tanana Valley value the stocking program because it provides a diversity of angling opportunities that normally wouldn't be present, particularly opportunities to catch highly valued species, such as rainbow trout and Arctic char, not native to the Tanana Valley.

In 2000, an estimated 25,200 anglers fished in the Tanana Valley, and they generated an estimated 121,785 angler-days of effort[1] (Walker et al. 2003). An estimated 55,091 angler-days (or 45%) of effort was directed toward stocked fish. The estimated harvests of stocked and wild fish in the Tanana Valley in 2000 were 66,123 and 20,890, respectively (Walker et al. 2003). An average (1998-2003) of approximately 733,000 fish are annually stocked into waters within the Tanana Valley (ADF&G U*npublished* data, ADF&G, Sport Fish Division, Fairbanks). Since 1990, stocked fish have represented 51 to 81% of the total estimated harvest of all game fish in the Tanana Valley and about 33 to 45% of the total estimated fishing effort (Skaugstad *In prep*). In 2000, about 75% of the total harvest of wild and stocked fish in the Tanana Valley was attributed to just two stocked species: rainbow trout and landlocked coho salmon (Walker et al. 2003).

The fishery at Quartz Lake (Figure 2) is the second most popular fishery in Region III[2] as measured by angler effort (17,812 angler days), and it provides the highest catch (76,000 fish) and harvest (26,000 fish) of any fishery in Interior Alaska (Howe et al. 2001d). During 2000, 28% of all fish harvested (both stocked and wild) in the Tanana Valley were caught in Quartz Lake (Walker et al. 2003). Rainbow trout are the main species stocked into Quartz Lake and sought after by Quartz Lake anglers. However, coho salmon, chinook salmon and Arctic char are also stocked, and coho salmon are the main species anglers catch during winter fishery (F. Parker, Alaska Department of Fish and Game, Delta Junction, personal communication).

QUARTZ LAKE FISHERY STATISTICS

In 2001, an estimated 4,113 anglers generated 8,325 angler-days of effort in Quartz Lake (Table 1). Catch and harvest of all stocked species during 2001 in Quartz Lake were 27,411 and 12,649, respectively. An estimated 14,821 rainbow trout were caught and 6,060 were harvested (Jennings et al. *In prep*). Since 1990, 52 to 73% of the catch and 48 to 72% of the harvest of stocked game fish in Quartz Lake was made up of rainbow trout (Table 1). Although rainbow trout typically comprise over 50% of the catch and harvest of stocked fish in Quartz Lake, catch and harvest of rainbow trout during 2001 was the lowest in 11 years. Although angling effort as measured by angler days was 25% lower in 2001 than it was during the previous year (2000), a similar number of anglers (4,628) caught and harvested over twice as many rainbow trout (32,358 and 14,358, respectively) during 2000, as during 2001 (Walker et al. 2003). Similarly, the estimated catch and harvest for landlocked salmon were 10,715 and 5,080 during 2001, while in 2000 catch and harvest were estimated at 27,464 and 9,866, respectively (Jennings et al. *In prep* and Walker et al. 2003). An estimated 1,509 Arctic char were both caught and harvested

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[1] Fishing effort (angler-days) for a location is defined as the estimated number of days fished by all anglers for that location (Mills 1990-1994; Howe et al. 1995, 1996, 2001a, b, c). Any part of a day fished by an angler is considered one angler-day.

[2] Region III is the administrative designation given to Interior Alaska and the North Slope. It encompasses a geographical area of approximately 1,357,080 sq. km, and includes the Copper, Yukon, Kuskokwim, and Tanana River Drainages, as well as the Seward Peninsula.

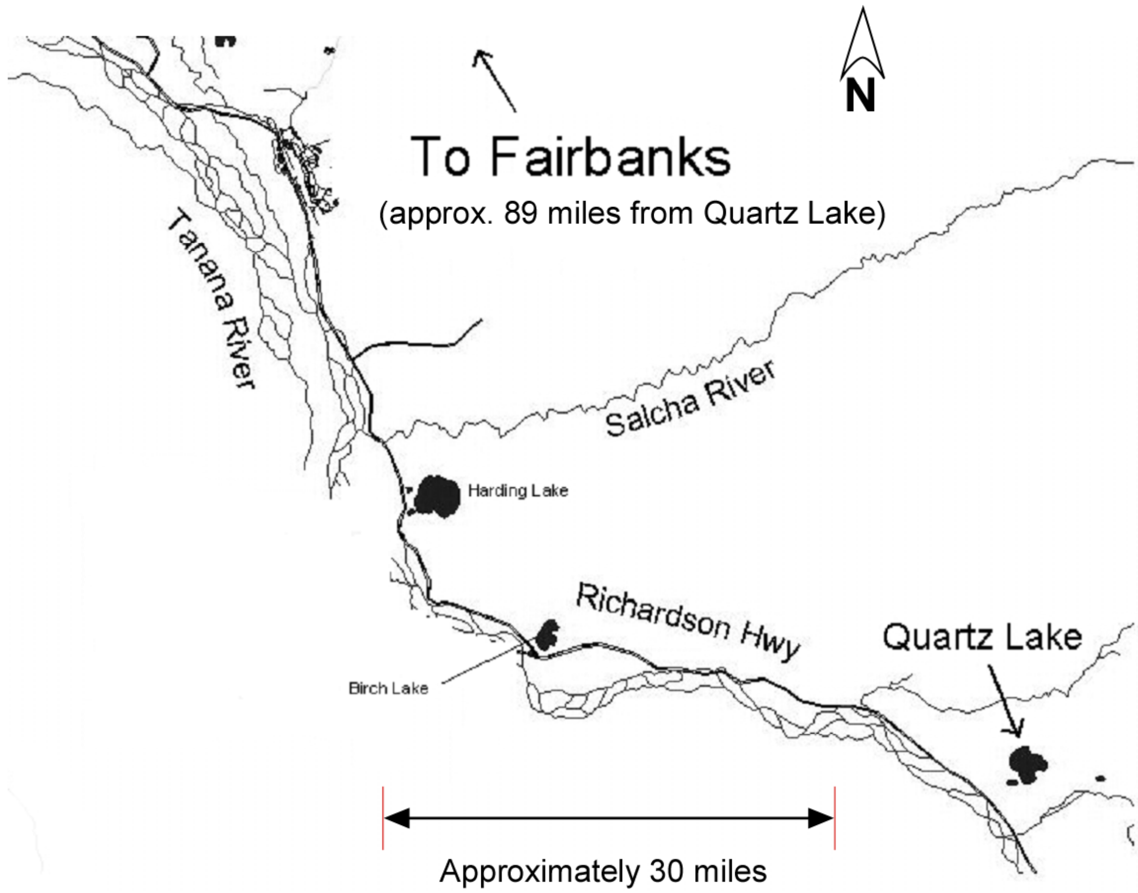


Figure 2.-Location of Quartz Lake in the Tanana Valley.

Table 1.-Effort, harvest, and catch statistics by species for Quartz Lake 1991-2001.

	Year										
	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Effort											
Number of Anglers	9,899	8,065	9,039	7,962	9,133	6,853	4,445	5,821	6,140	4,628	4,113
Number of Days Fished (effort)	15,478	13,486	17,613	14,031	17,569	14,163	6,956	10,175	17,820	11,047	8,325
Catch											
Rainbow trout	44,679	30,294	43,654	23,675	28,684	23,051	19,729	36,416	54,463	32,358	14,821
Coho/Chinook salmon	16,313	14,862	19,233	11,212	10,210	15,404	8,902	13,320	16,740	27,464	10,715
Arctic char	0	0	0	0	413	706	497	2,726	8,859	2,502	1,509
Total	60,992	45,156	62,887	34,887	39,307	39,161	29,1 8	52,462	80,062	62,324	27,411
Catch rate (catch / effort)	3.9	3.3	3.6	2.5	2.2	2.8	4.2	5.2	4.5	5.6	3.3
Harvest											
Rainbow trout	28,238	13,544	18,699	11,556	12,585	11,687	8,496	14,335	19,066	14,358	6,060
Coho/Chinook salmon	11,054	7,053	8,977	5,706	4,633	6,724	2,999	5,526	6,018	9,866	5,080
Arctic char	0	0	0	0	174	330	313	1,201	2,321	1,066	1,509
Total	39,292	20,597	27,676	17,262	17,392	18,741	11,808	21,062	27,405	25,290	12,649

during 2001, while in 2000, an estimated 2,502 char were caught and an estimated 1,066 were harvested (Jennings et al. *In prep* and Walker et al. 2003). Current daily bag and possession limits for Quartz Lake are 10 rainbow trout, 10 Arctic char, and 10 salmon (all species in combination), with no size restriction. Anglers can potentially harvest 30 fish per day.

From 1991 to 2001, the total annual effort on all stocked species in Quartz Lake ranged from 6,956 to 17,820 angler-days and averaged 13,333 angler-days (Skaugstad *In prep*). Average annual effort per surface acre for stocked species is about 4.3 angler-days while the stocking rate is approximately 200 fish (rainbow trout) per surface acre. The annual cost of producing and stocking fish (stocking cost) in Quartz Lake (1995-1999) ranged from about $71,547 to $114,060, while the cost-per-day of fishing (stocking cost / effort) ranged from $4.01 to $13.86 (Skaugstad 2001).

This publication reports the results of Quartz Lake rainbow trout population studies undertaken during both spring 2001 and autumn 2002. Results from test netting and additional Stocked Water Program activities are summarized in a separate report.

ABUNDANCE AND COMPOSITION OF AGE-1 RAINBOW TROUT IN QUARTZ LAKE, 2001

Rainbow trout are typically stocked as age-0 fingerlings into Quartz Lake, and usually have a summer to grow before their first winter. A year after their stocking, they would be considered age-1, and be approximately six or more inches long. By the end of their second summer in the lake, many fish would be > 6 in., and would begin to enter the fishery. Stocked rainbow trout in Quartz Lake can grow to be six or more years old and up to 24 inches in length (C. Skaugstad, Alaska Department of Fish and Game, Fairbanks, personal communication).

Although rainbow trout are available to anglers year-round in Quartz Lake, three seasonally distinct fisheries generally occur in the lake. These are 1) an early spring fishery where adult rainbow trout concentrate at nearshore open water leads in the lake ice cover and apparently attempt to spawn; 2) a summer fishery where anglers can catch fish from either shore angling or open-water boat angling; and 3) a winter fishery that generally begins in November and last into April, where anglers catch fish through the ice. Although the popularity of the Quartz Lake rainbow trout fishery has generally increased during the past 10 years (K. Alt, Alaska Department of Fish and Game, retired, personal communication), recent fishery trends indicate a decline in estimated harvest. For example, during 1999, 2000 and 2001, an estimated 19,000, 14,000, and 6,000 rainbow trout, respectively, were harvested from Quartz Lake (Howe et al. 2001d; Walker et al. 2003; Jennings et al. *In prep*). Accordingly, anglers reported to biologists catching fewer age-1 rainbow trout in Quartz Lake during 2000 than in previous years. A lack of age-1 rainbow trout could be the result of poor survival of stocked fingerlings (age-0). A similar phenomenon was reported from Dune Lake anglers, and observed during rainbow trout stock assessments at Dune Lake in 2000 (Skaugstad and Fish 2002). Dune Lake is similar to Quartz Lake in that both rainbow trout and coho salmon are stocked as fingerlings. However, at Tschute Lake (nearby to Dune Lake), where rainbow trout are stocked without coho salmon, test netting confirmed that age-1 rainbow trout were abundant a year after stocking (ADF&G, *unpublished* data, ADF&G, Sport Fish Division, Fairbanks).

Since 1977, both coho salmon and rainbow trout have been annually stocked into Quartz Lake. The lake is managed as a put-and-grow fishery, where both species are usually stocked as fingerlings, and grow to catchable sizes. However, during many years they were also introduced as subcatchables (20 grams and 4 to 6 inches long). Coho salmon live up to three years after being stocked, and in general, grow much faster than rainbow trout. Because of hatchery production challenges during the past four years, rainbow trout have been stocked at smaller sizes and later during the summer than previous years. As in Dune Lake (Skaugstad and Fish 2002), biologists hypothesized that previously stocked coho salmon prey on newly stocked juvenile rainbow trout in Quartz Lake, particularly if trout are stocked late in the season and do not have sufficient time to grow much during their first summer. Rainbow trout population studies were initiated to estimate the spring abundance of juvenile fish stocked the previous summer.

OBJECTIVES FOR 2001

The objective of the 2001 study was to estimate the abundance of age-1 rainbow trout in Quartz Lake, and determine if the estimated abundance was significantly less than 60,000 fish. A population of 60,000 age-1 rainbow trout would result from an assumed over-winter survival of approximately 40% from an introduction of 150,000 fingerlings during late summer; actual survival was unknown.

METHODS

A two-sample mark-recapture experiment was conducted during late May to mid-June to estimate the abundance of age-1 rainbow trout. The marking event (Event 1) occurred 29 May to 1 June 2001, and the recapture event (Event 2) occurred 18 to 22 June 2001. There was a two-week hiatus between events. To effectively sample the lake, four sampling quadrants were established (Figure 3), and each quadrant was sampled with a similar combination of capture gears. Capture gear consisted of fyke nets, tangle nets, and hoop nets. In total, there were 14 fyke nets utilized; four were deployed in each quadrant as either: 1) nearshore "typical" sets, 2) offshore floating sets, or 3) offshore sinking sets; two more fyke nets were deployed as nearshore sets having center leads.

Nearshore typical sets included four fyke nets that were set near the lakeshore in 1 to 2 m of water, where they rested on the lake bottom. The body of each fyke net was positioned parallel to shore. The open end of a fyke net was either 0.9 or 1.2 m^2, hoop size was 0.9 m diameter, and bar mesh size was 9 mm. Trap wings (7.5 m long by 1.2 m deep) connected to both sides of the open end were set to form a "V". One wing was anchored to shore, and a weight was attached to the other wing and positioned offshore. The cod end of each fyke net was pulled taut and weighted to the lake bottom.

A second set of four nets was deployed as "offshore floating," in which each net was "set" as a floating trap at the surface of the water. Spreader bars kept each net taunt, bullet floats kept each net floating, and an anchor line kept each net in place. The wings were not set, but rather were pinned to the sides of each net with cable ties. A third set of four fyke nets were deployed as "offshore sinking." These nets were deployed as the nearshore sets described above, only they were set at a greater distance offshore and in deeper water (1 to 3 m). Finally, two more fyke nets were set in Quadrants 1 and 2 (shallow part of lake) with extended center leads. Center leads consisted of additional netting (1 m deep) set off the opening of a fyke net for a distance of 33 m (100 feet). Their purpose was to funnel fish towards the fyke net. During Event 2, an additional two fyke nets were deployed as floating sets in the middle of the lake, and were

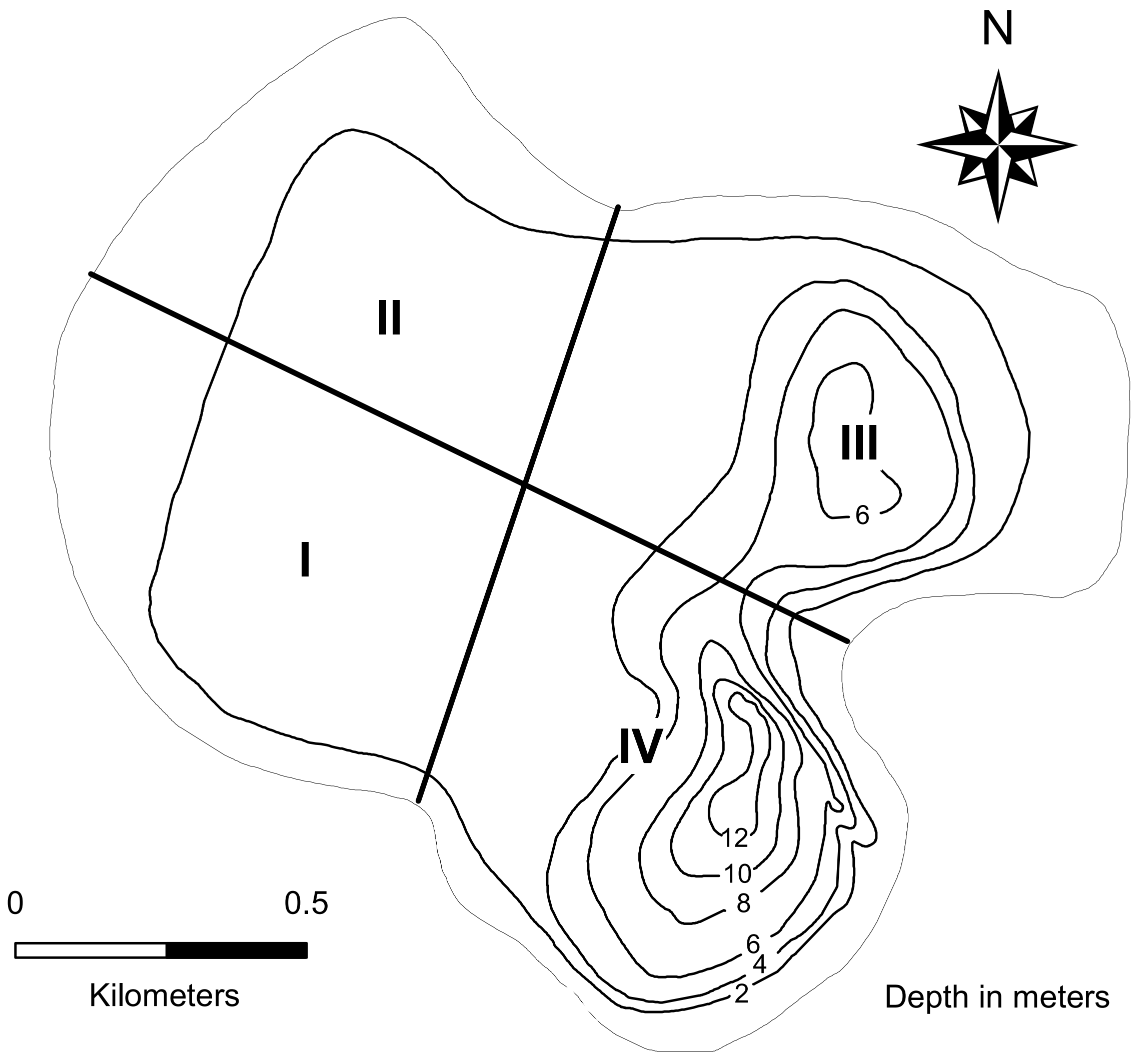


Figure 3.-Quartz Lake and demarcation of sampling quadrants.

attached to each other by a 33m center lead. Overall, 14 fyke nets were deployed during Event 1, while 16 were used during Event 2. All fyke nets were checked every 24-hrs during each event.

Tangle nets were 45 m (150 ft) long by 5.4 m (18 ft) deep, and were made of 13 mm (0.5 in) bar fine thread monofilament. Mesh size was small to ensure that fish were captured by entanglement around the mouth and not by the gill covers. One tangle net was a “floater,” where the float line floated on the surface and the lead line was suspended 5.4 m below the surface. The other tangle net was a “sinker,” where the lead line rested on the lake bottom and the float line was suspended 5.4 m above the lake bottom. The floater had a triple float line and 30 lb lead line. The sinker had a double float line and a 70 lb lead line. Tangle nets were usually set either parallel or perpendicular to shore, in water 3 to 11 m deep. The tangle nets were moved to various locations to ensure sampling canvassed all habitat types. Tangle nets were set for one-half hour to one hour, and were used between 0900 to 1800 hours.

Hoop nets consisted of 2 m by 0.5 m cylindrical traps, made of 0.5 inch Vexar ™ material. Each trap had an inverted opening at either end, and was baited with salmon eggs. Hoop nets were set at varying depths (1 to 12 m) following a transect that intersected Quadrants 3 and 4.

Each captured fish was marked with unique fin clips to identify the event in which it was captured and the gear used for its capture**.** Fish captured for the first time during Event 1 were marked with upper caudal fin clips, while fish captured for the first time during Event 2 were clipped on the lower caudal fin (whether they had upper caudal fin clips or not). Investigators also attempted to mark fish with additional fin clips by capture gear; i.e. fish captured nearshore fyke nets were marked with ventral fin clips, fish captured in hoop traps were marked with pectoral fin clips, and fish captured in tangle nets were marked with adipose fin clips. However, investigators occasionally forgot to clip fins other than the upper or lower caudal fin, and some fish were missing the appropriate fin to clip. Therefore analyses based upon additional fin clips were not included in estimation procedures.

All captured fish were measured to the nearest 1 mm. In this report, all fish-length measurements are FL unless noted otherwise. As described above, rainbow trout are stocked as fingerlings (age-0) into Quartz Lake. During the following summer, fish are age-1 and are typically less than six inches long. Age-1 fish are easily discerned from age-2 and older fish by their distinct size range, so scale samples were not collected from any fish handled.

The assumptions necessary for accurate estimation of abundance in a closed population and the testing of these assumptions are described in Appendices A and B. Depending on the outcome of these tests, appropriate adjustments were made to the abundance estimation procedures, as outlined in Appendix B.

Chapman’s modification of the Petersen estimator (Chapman 1951; Seber 1982) was used to estimate the abundance of the age-1 rainbow trout population (≤ 200 mm):

$$\hat{N} = \frac{(n_1+1)(n_2+1)}{(m_2+1)} - 1 \tag{1}$$

where: $\hat{N}$ = the abundance of rainbow trout in Quartz Lake; n_1 = the number of rainbow trout marked and released during the marking event (Event 1); n_2 = the number of rainbow trout examined for marks during the recapture event (Event 2); and, m_2 = the number of marked rainbow trout recaptured in the recapture event. If a fish was captured more than once during a sampling event, the subsequent capture(s) was noted in our records but it was not measured nor was the subsequent capture(s) used in data analysis or abundance estimation.

Variance of Chapman's modified estimator was calculated using (Seber 1970; Wittes 1972):

$$V\left[\hat{N}\right]=\frac{(n_1+1)(n_2+1)(n_1-m_2)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \tag{2}$$

All data collected and analyzed are archived in files listed in Appendix C.

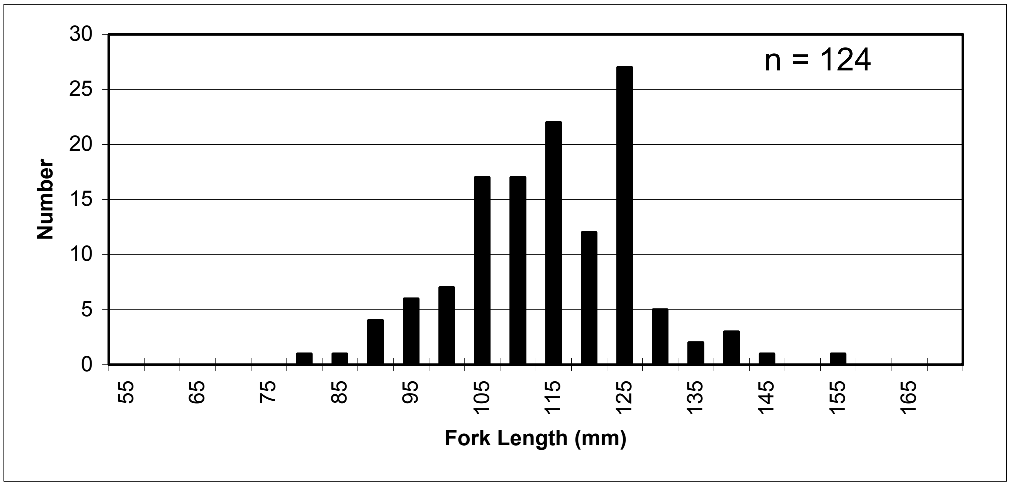
RESULTS

Age-1 rainbow trout were easily distinguished from older fish by their size. Age-1 fish ranged in size from 55 to 170 mm FL (≈6 inches or less), and averaged 111 mm FL (Figure 4). Age-1 (≤ 170 mm FL) and age-2 fish (≈ 180 to 295 mm FL) are apparent in the bimodal size distribution. Only fish ≤ 170 mm FL were utilized during abundance estimation procedures.

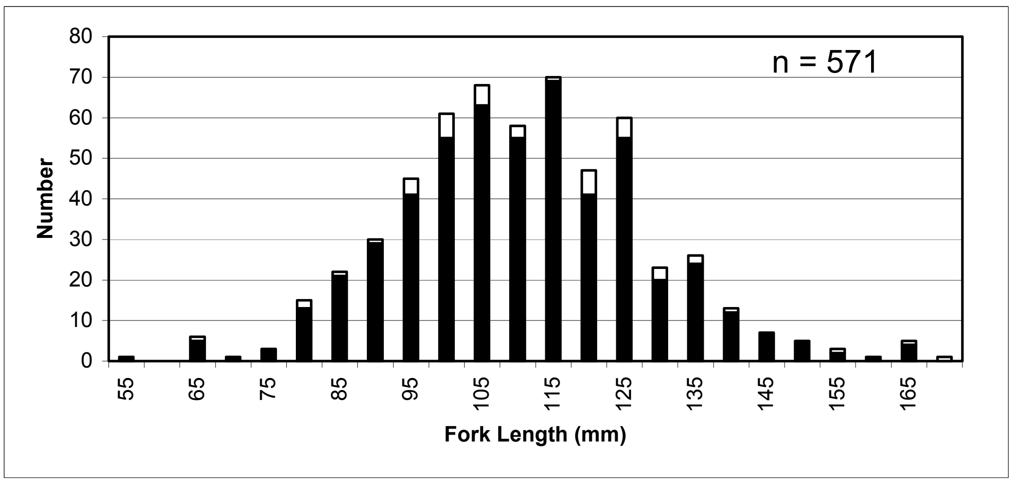
During Event 1, 124 rainbow trout ≤ 170 mm were captured, marked, and released (length distribution shown in Figure 4a). During Event 2, 571 rainbow trout were captured, 44 of which were recaptures (length distributions shown in Figure 4b). Overall, 651 unique fish (ranging in size from 55 mm to 560 mm FL) were handled during the experiment (Figure 4c). Two unmarked rainbow trout died during Event 1, while 3 fish died during Event 2 (1 marked and 2 unmarked). The dead fish in Event 1 were not included in the experiment, while those from Event 2 were included.

During this experiment, there was no natural immigration or emigration because the lake was closed (no inlet or outlet). However, approximately 5,000 large catchable (≈9 inches or 230 mm FL) rainbow trout, as well as 58,000 fingerling (≈3 inches) coho salmon were stocked during the hiatus. The larger rainbow trout were not included in the abundance estimate (they were readily distinguished from fish ≤ 170 mm FL), and coho fingerlings were easily distinguished from fingerling rainbow trout by their lack of deeply colored parr marks and fin coloration. Fingerling rainbow trout were not stocked during 2001 until after the mark-recapture experiment was completed.

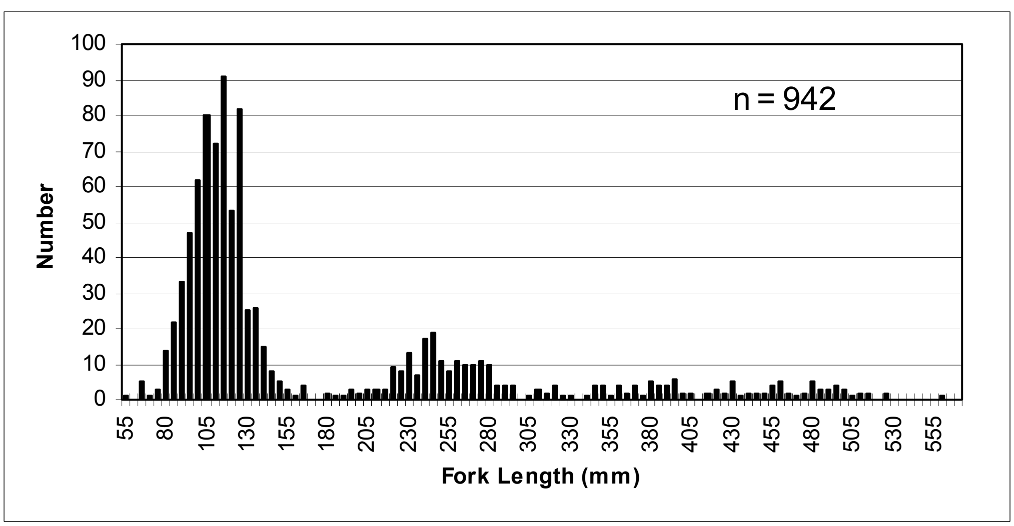
Plots of the cumulative distribution functions (CDFs) were generated for lengths of fish captured during either event (Figure 5), and Kolmogorov-Smirnov two-sample tests were performed with lengths of fish marked during the first event, fish captured during the second event, and marked fish recaptured during the second event. Although the shapes of the CDFs for fish captured in Events 1 and 2 are similar, fish captured in Event 2 were generally smaller than fish captured in Event 1, as shown by the CDF for Event 2 being shifted to the left (Figure 5). The CDFs for unmarked fish and fish recaptured in Event 2 are also shifted to the left. Results of K-S tests indicated that the CDFs of fish marked during Event 1 and fish examined for marks during Event 2 were significantly different ($D = 0.17$, $P = 0.004$ for marked vs. examined fish). However, K-S tests also indicated that lengths of fish marked and lengths of fish recaptured were not significantly different ($D = 0.19$, $P = 0.10$). Further contingency table analysis by size class indicated significant difference in the probability of recapture of marked fish (Table 2). We did not detect any clear trend in differential vulnerability to sampling gear by size of 1 year old rainbow trout ranging from 55 to 170 mm. The significant differences observed were primarily a result of lower observed probability of rainbow trout in the 110 mm and 115 mm size classes.



a)



b)



c)

Figure 4.-Lengths of rainbow trout captured during Quartz Lake mark-recapture experiment, 2001; a) Event 1 or Marking Event; b) Event 2 or Recapture Event, with recaptures (n = 44) shown in white; c) all unique rainbow trout handled during 2001.

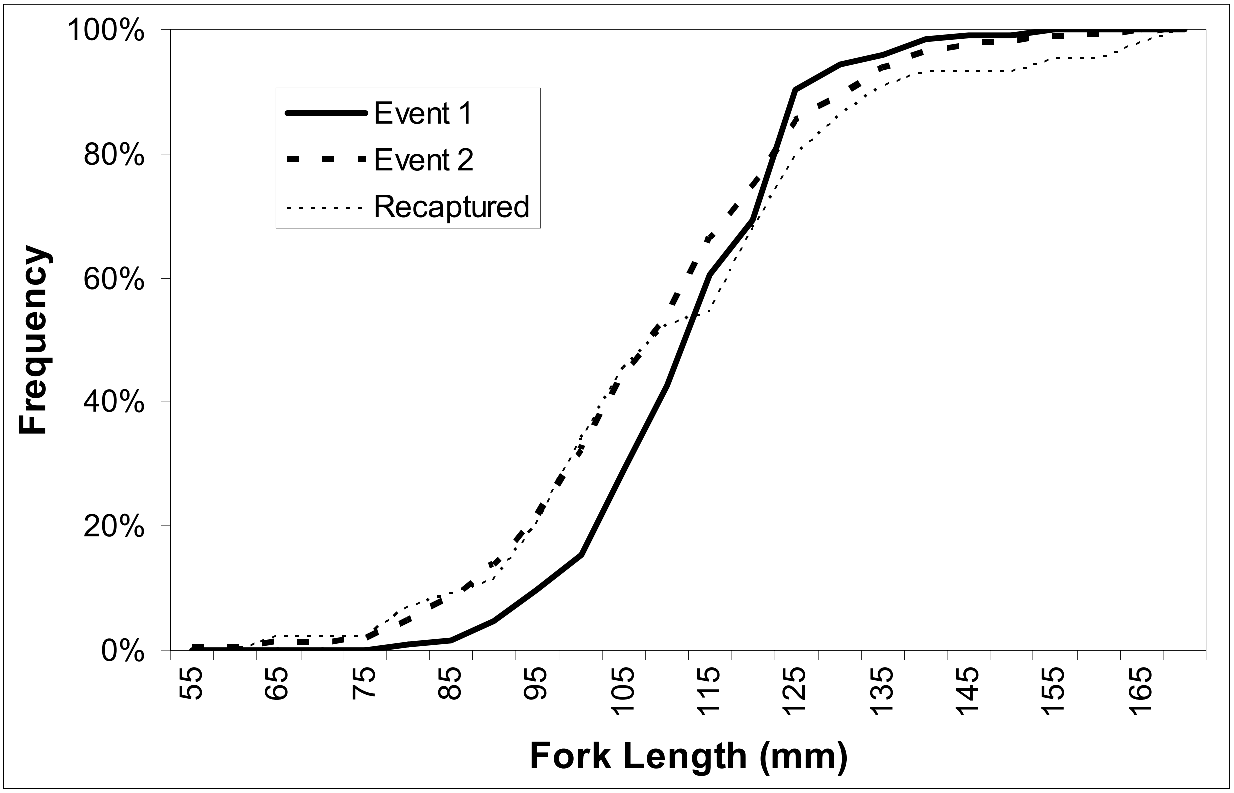


Figure 5.–Cumulative distribution function of lengths from rainbow trout ≤ 170 mm FL captured during the mark-recapture experiment at Quartz Lake (D = 0.17, P = 0.05 for marked vs. unmarked fish; D = 0.19, P = 0.10 for marked vs. recaptured fish).

Table 2.-Contingency table analysis of marked and recaptured fish ≤ 170 mm FL and divided into size classes (first test includes fish 105-110 mm FL, while the second test excludes this size class).

Size Class (mm FL)	Marked (E1)	Recaptured (m2)	E1-m2	Percent	Size Class (mm FL)	Marked (E1)	Recaptured (m2)	E1-m2	Percent
N (55-105)	*36*	*20*	16	*0.56*	*n (55-105)*	*36*	*20*	16	*0.56*
N (110-115)	*39*	*4*	35	*0.10*	n (120-170)	49	20	29	0.41
n (120-170)	49	20	29	0.41					
Totals	124	44	80	100	**Totals**	85	40	45	100
χ^2		17.79			χ^2		1.26		
df		2			Df		1		
p		<0.01			*P*		0.26		

Fish in the 110 mm and 115 mm size classes constituted 31% of first sample and 22% of the second sample in the mark recapture experiment. No significant difference in probability of recovery was observed between marked fish 105 mm and smaller, and those 120 mm and larger. No clear trend in differential vulnerability to sampling gear by size of juvenile rainbow trout (ranging from 55 to 170 mm) was discernable. The observed differences in capture probability between the 110-115 mm size classes and other size classes was considered a rare random event with no biological or logistical bearing on the interpretation of results.

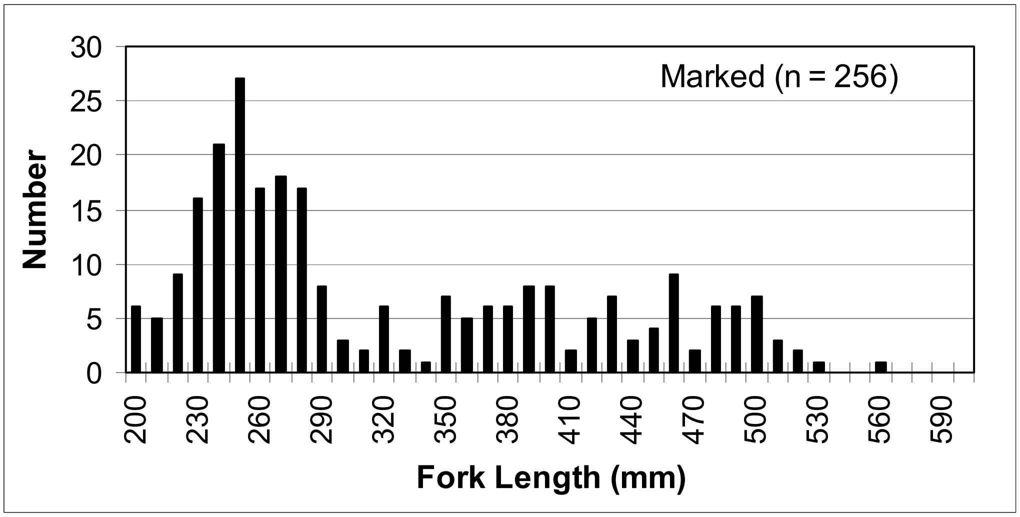
Because K-S tests are sensitive to growth occurring during the experiment, and because we were interested in focusing the abundance estimate on age-1 fish, we also conducted Chi-squared (contingency table) tests on the data. Although not as precise as using K-S tests, this method is appropriate in this situation because it is less sensitive to growth of fish between sampling events, there was one age class in the population (age-1), and all fish were assumed to be vulnerable to the capture gear. Length data from marked fish during Event 1 and fish examined for marks during Event 2 were partitioned at the mean (≈110 mm FL) into large and small fish. Using contingency table analyses, no size bias during the experiment was detected for age-1 fish (χ^2 = 2.53, df = 1, P = 0.16 for recaptured vs. not recaptured fish and χ^2 = 0.80, df = 1, P = 0.46 for marked vs. unmarked fish; Table 3). Therefore, data were not size stratified to estimate abundance.

Table 3.-Contingency table analysis of recapture rates and marked:unmarked lengths of fish ≤ 170 mm FL and divided at mean length (110 mm FL) into two groups.

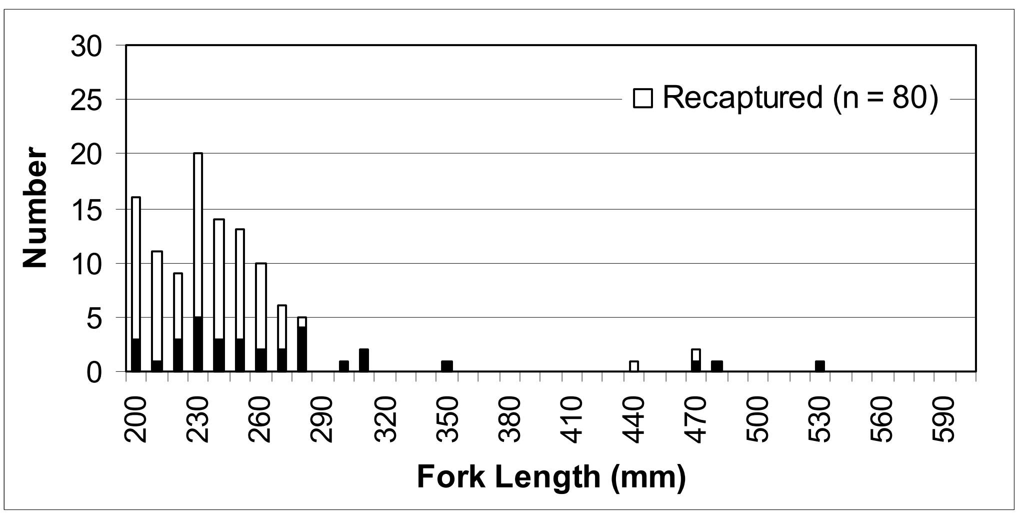
	Recaptured	Not Recaptured	Totals	Marked	Unmarked	Totals
N(< 110)	*23*	*30*	53	*23*	*312*	335
N (>110)	*21*	*50*	71	*21*	*215*	236
Totals	**44**	**80**	**124**	**44**	**527**	**571**
χ^2		2.53			0.80	
df		1			1	
p		0.16			0.46	

Although not part of the objective of this study, captures of fish age-2 and older were particularly greater during Event 1 than during Event 2 (Figure 6). Although the number of recaptures was 80 fish, most were between 200 and 280 mm FL. Few fish > 280 mm FL were handled during Event 2.

Likewise, examination of recapture rates and marked to unmarked ratios of large fish (≥ 200 mm FL), with a mean length of 292 mm FL (for fish handled during both Events 1 and 2), revealed size selectivity during the experiment (χ^2 = 78.04, df = 1, P = <0.01 for recaptured vs. not recaptured fish, and χ^2 = 8.75, df = 1, P = <0.01 for marked vs. unmarked fish; Table 4). Although fish of this size (and age) were not part of the study objectives, these results are presented to demonstrate the potential for lack of independence between size and probability of capture.



a)



b)

Figure 6.-Lengths of rainbow trout ≥ 200 mm FL marked during Event 1 (a) and examined during Event 2 (b) during Quartz Lake mark-recapture experiment, 2001 (total fish examined in Event 2 was 113; recaptures depicted in white).

Table 4.-Contingency table analysis of recapture rates and marked:unmarked lengths of fish ≥ 200 mm FL and divided at mean length (292 mm FL) into two groups.

	Recaptured	Not Recaptured	**Totals**	Marked	Unmarked	**Totals**
n(<292 mm FL)	*78*	*66*	**144**	*78*	*26*	**104**
n (>292mm FL)	*2*	*110*	**112**	*2*	*7*	**9**
Totals	**80**	**176**	**256**	**80**	**33**	**113**
χ^2		78.04			8.75	
df		1			1	
P		<0.01			<0.01	

Table 5.-Rainbow trout ≤ 170 mm FL marked, examined, and recaptured by Quadrant location in Quartz Lake, 2001.

Quad	Mark	Exam(n_2)	Recaps(m_2)	m_2:n_2
I	31	65	3	0.05
II	22	27	3	0.11
III	35	266	15	0.06
IV	36	212	22	0.10

Movement of fish ≤ 170 mm FL between quadrants could not be documented or examined because there were no distinguishing marks given that were unique to a particular quadrant of capture. Most fish examined in the second event were handled in Quadrants 3 and 4 (Table 5). Ratios of fish recaptured (m_2) to fish examined (n_2) were not significantly different between quadrants ($\chi^2 = 5.12$, df = 1, P = 0.16).

Capture probability varied by gear type; most rainbow trout ≤170 mm FL were captured and recaptured with nearshore fyke nets, and not with all types of capture gear utilized (Table 6). Proportions of fish captured by gear type are reported as the fraction of the total number of fish caught during each event, and not by recapture rate. For example, during the Event 1, most fish ≤170 mm FL (75%) were captured in nearshore fyke nets having center leads, while 23% were captured in typical nearshore fyke net sets, and less than 1% were captured in either offshore fyke nets, hoop nets or tangle nets (Table 6). During Event 2, 73% of rainbow trout were captured in typical nearshore fyke nets (without center leads), while 13% were captured in nearshore fyke nets with center leads, and ≈14% were capture in offshore fyke nets (Table 6). None of the "floating" fyke nets, nor hoop nets, captured rainbow trout ≤ 170 mm FL during either Events 1 or 2.

Table 6.-Number and percentage of rainbow trout ≤ 170 mm FL captured during Events 1 and 2 by gear type (NSFY-C = nearshore fyke net with center lead, NSFY = nearshore fyke net, OSFY = offshore fyke net, Float = floating fyke net and 2FY-C = two fyke nets connected by a center lead).

Event		Gear Type						
		NSFY-C	NSFY	OSFY	Float	Hoop	Tangle	2 FY-C
1	*n*	93	28	1	0	0	2	
	%	0.75	0.23	0.008	0	0	0.016	
2	*n*	74	417	77	0	0	0	3
	%	0.13	0.73	0.14	0	0	0	0.01

The estimated abundance of age-1 rainbow trout (55 to 170 mm FL) was 1,588 fish (SE = 180). Survival to age-1 (following equations in Appendix D) of fish stocked during 2000 was estimated to be 0.005 ($V = 2.6^{-0.7}$); or 0.5% .

During the experiment, 1,003 landlocked coho salmon were also captured. A total of 248 fish ≥ 200 mm FL were handled during the experiment; 219 coho salmon were handled during Event 1, while during Event 2, 30 fish were handled (29 unmarked and 1 recapture). As with rainbow trout during Event 1, most coho salmon were captured in nearshore fyke nets having center leads. Because fish are easily stressed when crews handle large numbers of fish at any one particular time, coho salmon were opportunistically measured when time allowed, and not in a systematic manner. Coho salmon less than 200 mm FL were typically not measured during Event 2. Therefore, a meaningful abundance estimate was not generated for coho salmon. The size of coho salmon handled, however, ranged from 67 mm FL to 330 mm Fl, and averaged 195 mm FL (those greater than 200 mm FL averaged 276 mm FL). The smaller sized fish (i.e., fish < 230 mm FL) were determined to be age-1, and were easily distinguished from older fish in the multi-modal distribution. Larger coho salmon (> 230 mm FL) were age-2 and were a cohort of fish stocked during 1999, beginning their third summer in Quartz Lake (Figure 7). For comparison, lengths of rainbow trout handled are also shown in Figure 7. Coho salmon are larger at age than rainbow trout, particularly during the first two years of life. For additional comparison,

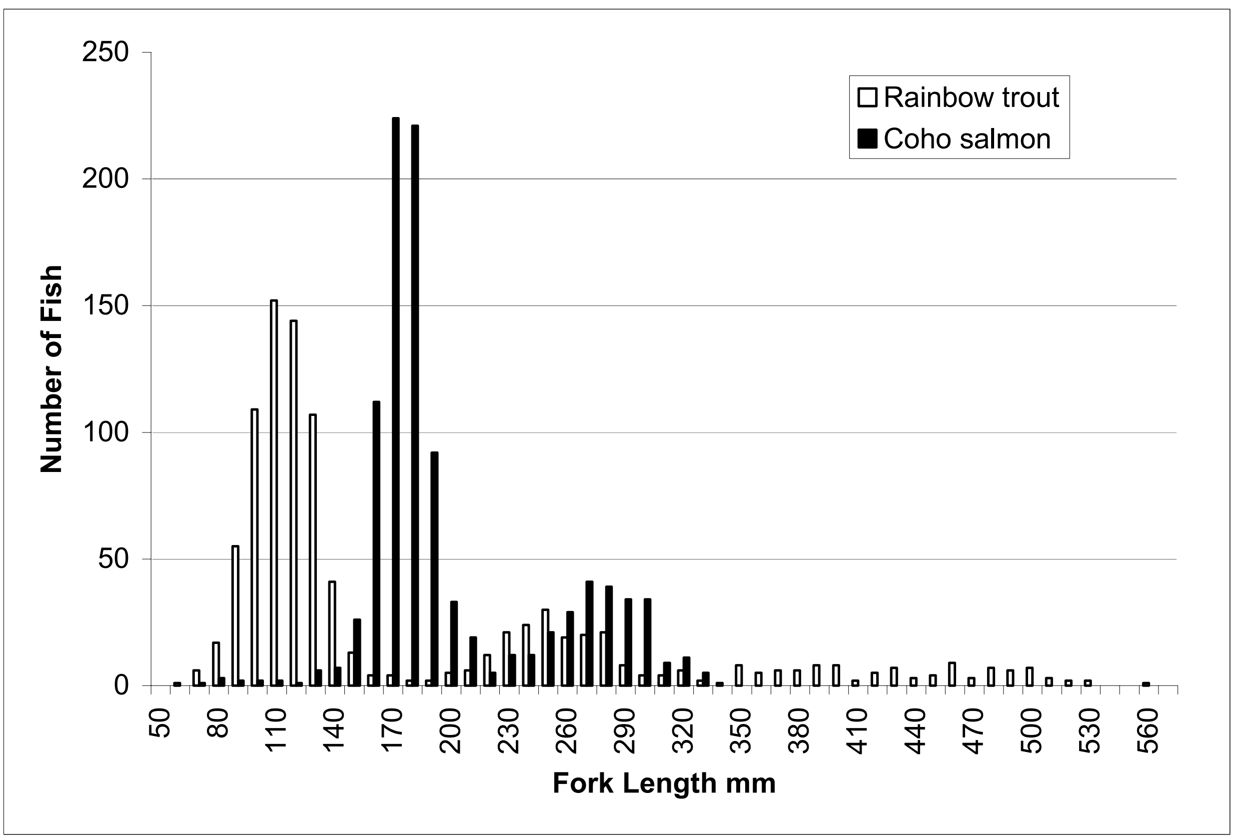


Figure 7.-Length distribution of Quartz Lake rainbow trout and coho salmon handled during Events 1 and 2, 2001 (rainbow trout n = 653, coho salmon n = 1,003).

Figure 8 also shows the average size at stocking of both coho salmon and rainbow trout, from 1997 to 2002. Mean size (4.3 in) of coho salmon at stocking into Quartz Lake was larger than mean size of rainbow trout (2.1 in).

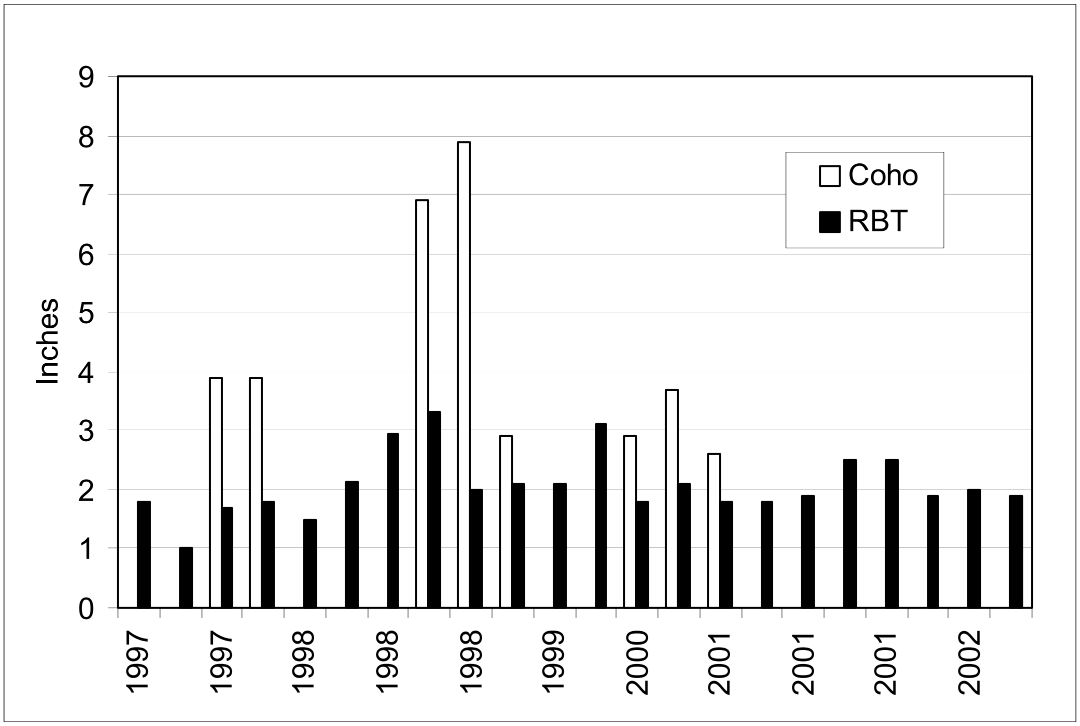


Figure 8.-Average length of coho salmon and rainbow trout fingerlings stocked into Quartz Lake, 1997-2002 (see Appendix E for numbers of fingerlings stocked into Quartz Lake each year).

DISCUSSION

This mark-recapture experiment was performed during early to mid-June to take advantage of the propensity of rainbow trout that utilize nearshore waters in late spring. Results from K-S tests indicated that the length distribution of rainbow trout marked during Event 1 was significantly different from that of rainbow trout sampled during Event 2. This difference was due to a greater number of small fish being caught during Event 2. Fish behavior (i.e., foraging behavior, or avoidance of predators in offshore waters and littoral zones) may have concentrated juvenile fish into shallow waters during mid-June where fyke nets were most effective at capturing fish. This possible explanation is also consistent with numbers of larger (and older) fish observed. Catches of fish > 280 mm FL, were negligible during Event 2, suggesting that larger fish moved to deeper waters during the hiatus. Even though more age-1 fish were handled during Event 2, a complete evaluation of diagnostic tests indicated that size biases were not detected in Event 2 sampling, and that stratification during the abundance estimation procedures was not necessary. Angling also likely occurred during the experiment but it is unknown how many fish were harvested, or what the marked to unmarked ratio of the harvested fish was. If fishing and other mortality was the same for both marked and unmarked age-1 fish then the abundance estimate was unbiased and germane to Event 1.

Because of the complexity of multiple gear types, species, fin clips, net locations, lake sampling quadrants and crews performing the sampling involved, mistaken fin clips and mislabeled net locations were identified in the data. In addition, fish were not marked uniquely enough, such as between fish captured in fyke nets having center leads vs. fyke nets not having center leads (although both were located in shallow nearshore water). Furthermore, there was inconsistency in net setting environment (depth, distance from shore, substrate characteristics, etc.), as gear types were not used in identical habitat within each quadrant, but were set to maximize catch.

Fishing success, particularly during Event 2, was greatest in Quadrants III and IV, while captures of fish were greater in nearshore waters during both events than it was in offshore waters. It is unclear why nearshore fyke nets, having a center lead attached captured the greatest number of fish during Event 1, while nearshore fyke nets without center leads captured more fish during Event 2. Quadrant III and IV were located in the parts of Quartz Lake that contain the two deepest basins (≈8 and 12 meters deep). It is interesting that more juvenile rainbow trout (≤ 200 mm FL) were captured in these particular locations, within nearshore shallow waters, even though Quadrants I and II contain a greater area of shallow habitat with patches of submergent vegetation, where nearshore nets fished best.

Even with peculiar capture patterns in nearshore nets, the abundance estimate is likely a reliable indicator of the juvenile rainbow trout population status. Because catches of fish were greatest nearshore, and a preponderance of gear was utilized throughout the lake, it is unlikely a large portion of the juvenile rainbow trout population remained unsampled in deeper waters. Accordingly, the estimated abundance suggests that fingerling rainbow trout survival was less than 1%, from 2000 to 2001 (based on the number of fish that were stocked in 2000; Appendix E). As a result, future recruitment from this age class to the sport fishery is expected to be very low.

One possible explanation for the low abundance of age-1 rainbow trout is mortality from transport stress prior to stocking. However, because low abundance of juvenile fish has been suspected for the recent past few years, it is unlikely transport stress would consistently result in large mortality year after year. A second explanation for the low abundance of age-1 rainbow trout is predation by landlocked salmon, Arctic char, and older rainbow trout. A third explanation includes observations that Quartz Lake approaches near-winterkill conditions during periods of ice cover, and anecdotal evidence that Quartz Lake may occasionally winterkill (K. Alt, Alaska Department Fish and Game, retired, personal communication). Low dissolved oxygen concentrations during mid-to-late winter (such as those depicted in Figure 9) may stress fish and cause mortality. However, it is unknown if stress from low levels of dissolved oxygen affects fish in Quartz Lake differently based on their size. Regardless, investigators have not observed complete winterkill conditions (where dissolved oxygen is less than 1.0 mg/l throughout the water column), nor aggregates of dead fish after break up. Lastly, a fourth explanation for poor fingerling survival would be a combination of all factors mentioned above, particularly both predation and winterkill mortality.

Since 1977, coho salmon and rainbow trout have lived sympatrically in Quartz Lake. As shown in Figure 7, coho salmon appear to grow more quickly than rainbow trout, when stocked as similar sized fingerlings.

Coho salmon are popular during the winter ice fishery because they are aggressive feeders and readily strike angling gear. Although formal studies of food habits have not been conducted on

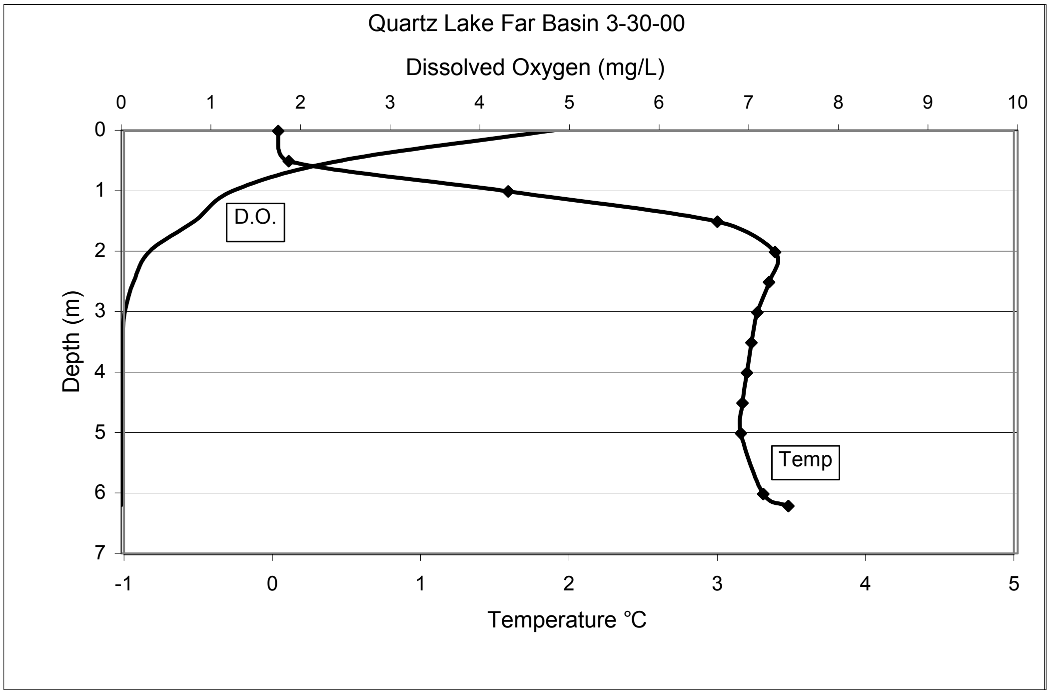


Figure 9.-Dissolved oxygen and temperature profile in the far basin (Quadrant III) of Quartz Lake during late winter, 2000.

Quartz Lake fish populations, larger stocked fish, such as coho salmon, likely prey extensively on smaller stocked fingerlings. Stocked landlocked salmon, having fingerling rainbow trout in their stomachs, have occasionally been captured (K. Alt, Alaska Department Fish and Game, retired, personal communication). The only smaller forage fish inhabiting Quartz Lake are lake chub, *Couesius plumbeus*. The abundance of lake chub is unknown, although biologists suspect they are not as numerous as the annual introductions of rainbow trout fingerlings (325,000 fish). Quartz Lake was treated with rotenone in 1970. Because the lake lacks inlet and outlet streams, the reappearance of lake chub in Quartz Lake may be the result of anglers using them as live bait for fishing (even though this is not legal). Lake chubs may also not be a preferred forage item for larger predators. For example, the authors have observed lake chub to be consistently numerous each year in Little Harding Lake and Lost Lake, even though both lakes contains an abundant populations of large rainbow trout. Fingerling rainbow trout are probably the ideal prey size for many larger stocked fish. Overall, there are four species of piscivorous fish in Quartz Lake: Arctic char, chinook salmon, coho salmon, and rainbow trout. Avian predators (waterfowl and birds of prey) are also present. Consequently, predation on stocked fingerlings is probably intense. When juvenile rainbow trout (≈40 to 50 mm FL, or 0.5 to 1 gram) have been stocked into barren (fishless) ponds during mid-summer, their pre-winter recovery in fyke nets has typically been 20% or greater (ADF&G *Unpublished*). Before stocked fish reach catchable sizes, they likely feed on aquatic invertebrates. At some point in their life history (perhaps at age-2 or older), they may switch to feeding on larger prey items, such as larger aquatic invertebrates and stocked fingerlings. For example, Arctic char were introduced into Quartz Lake beginning in 1991, and have been stocked at both fingerling and subcatchable sizes. Once, after several years of growth, these fish reach catchable sizes, they likely switch to feeding on other fingerlings stocked into the lake, particularly smaller fingerling rainbow trout. Although stomach contents of Quartz Lake Arctic char have not been examined for fingerling fish, this hypothesis is consistent with what investigators have observed in Harding Lake, where larger Arctic char feed heavily on smaller (2 to 4 inch) least cisco, *Coregonus sardinella* (M. Doxey and C. Skaugstad, Alaska Department of Fish and Game, Fairbanks, personal communication). Coho salmon were also stocked into Harding Lake from 1968 to 1981. The decline of least cisco in Harding Lake during 1977 was partly attributed to predation by coho salmon (Hallberg 1978). However, the subsequent recovery of the cisco population in Harding Lake not only coincided with the cessation of coho salmon fingerling stocking, but also an increase in lake water level (and vegetated lakeshore habitat available for cover for juvenile fish), and a rise in lake burbot harvest (Doxey 1991b). Rainbow trout fingerlings have been stocked into Quartz Lake since 1971, and have been stocked as late as August during many years. Angler effort and consequently departmental fish population studies have increased during recent years, as the fishery has developed and grown. It is possible that the rainbow trout population has experienced severe declines during past years, but missing cohorts have gone unnoticed. Stocking subcatchables during various years may have also masked such cohort failures in the past. Additionally, two new predators (Arctic char and chinook salmon) were added to the lake, beginning in 1991. Current water and heat shortages at Fort Richardson Hatchery may be indirectly influencing fingerling survival because rainbow trout fingerlings are stocked later in the summer, and at smaller sizes, than in the recent past. As a result, rainbow trout fingerlings may not have sufficient time grow to a size where they successfully compete or avoid predation during their first summer in the lake. Based on what investigators observed in other stocked lakes, failure to grow much during their first summer in a lake (the result of being stocked later in the year), and subsequent predation by other stocked fish, are the most plausible reasons for poor survival of fingerling rainbow trout.

Subcatchable-sized rainbow trout (≈4 inches) were stocked annually from 1987 to 1992, and again during 1997. Although Doxey (1991a, 1992) found that fingerlings stocked during summer of one year, and subcatchables stocked during spring of the following year had similar mean lengths and size ranges after their first summer in Quartz Lake, it is likely rainbow trout suffer less predation, and are able to compete better for forage, when stocked as subcatchables instead of fingerlings. It is also possible that a cohort of fish stocked early in a given growing season (May/June), regardless of size, will have greater survival to the following spring than fish stocked late in the growing season (i.e., August). Considering subcatchable rainbow trout are not only larger at stocking (since they spend nine months or more in a hatchery, compared to three months that fingerlings are reared), but also can be stocked during spring after ice-out, they may be the ideal lifestage of rainbow trout to sustain the Quartz Lake fishery. Figure 10 depicts the annual rainbow trout harvest and years of subcatchable introductions. An increase in harvest is seen two years after subcatchables are stocked. Generally, fish survive better and contribute to a fishery more, when they are stocked at larger sizes (Doxey 1991a and 1992). The current harvest level (≈ 14,000 or more rainbow trout) is insufficient for the stocked fingerling population to maintain an adequate number of catchable rainbow trout, if fingerling survival continues to be poor. Stocking subcatchable- or catchable-sized rainbow trout into Quartz Lake in quantities to exceed the recent estimated harvest may prevent anticipated declines in rainbow trout availability in the sport fishery.

ABUNDANCE AND COMPOSITION OF AGE-2 RAINBOW TROUT IN QUARTZ LAKE, 2002

INTRODUCTION

The abundance of age-2 and older rainbow trout in Quartz Lake was estimated during 2002 with a mark-recapture experiment, to ascertain the availability of catchable sized fish to sport anglers. The study focused on age-2 and older rainbow trout (which range in size from approximately six to 20 inches or more) because 1) they are the age classes that contribute to the sport fishery, and 2) the age-2 class was created from age-0 fingerlings stocked during 2000, and age-1 catchables stocked during 2001. During 2001, the survival of age-0 fingerlings to age-1 was less than 1%. To ensure a continued sport fishery, managers responded by introducing 7,837 age-1 catchables into the lake during 2001, of which 64% were uniquely marked with left ventral fin clips. It was expected that catchable-sized fish stocked during 2001 sustained the fishery, while fingerling survival continued to be low. Abundance was estimated to identify 1) the overall number of rainbow trout available to sport anglers, 2) the number to age-2 rainbow trout, and 3) the number of surviving age-2 rainbow trout that were introduced as age-1 catchables during 2001. This discriminatory approach was necessary to ascertain if catchables stocked during 2001 made immediate contributions to, and sustained, the sport fishery in Quartz Lake.

Doxey, (1989, 1992) found that recapture rates of marked fish in Birch and Quartz lakes were greater during sampling events in September, than in August or October. Havens et al. (1991) found that mark-recapture estimates of rainbow trout in Big Lake, Alaska, were roughly half during June of what they were during the following October, for the same population. Similarly, Skaugstad and Fish (2000) found that catches of rainbow trout in nearshore fyke nets in Little

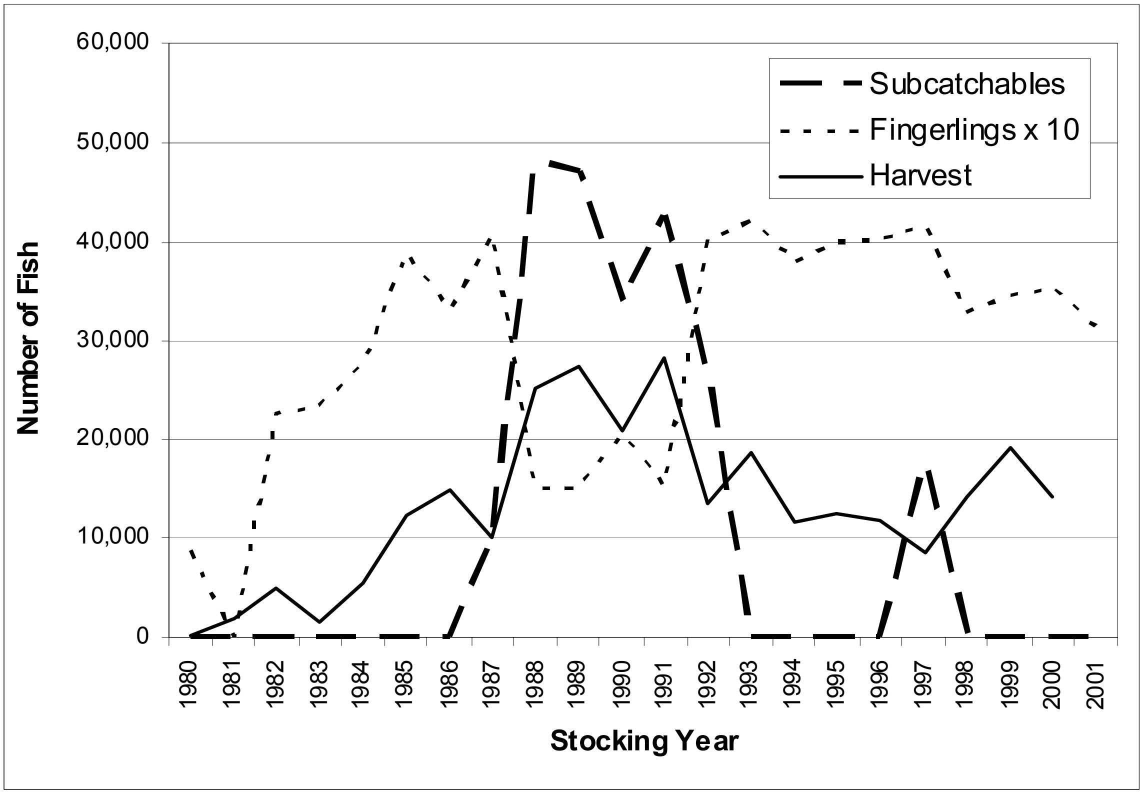


Figure 10.–Rainbow trout lifestage stocking and harvest in Quartz Lake, 1980 – 2000. The number of fingerlings stocked each year was scaled by 1/10th to illustrate stocking trends.

Harding Lake declined during late- June and July. Rainbow trout stocked into lakes apparently inhabit limnetic (pelagic) waters during July and August, where water temperatures are lower, dissolved oxygen is adequate and forage may be available. During September, when lakes become isothermal, fish appear to move into nearshore waters, where fyke nets are most effective at capturing fish. Mark-recapture experiments are typically planned for late spring (June) or early autumn (September) to minimize bias associated with incomplete mixing between marked and unmarked fish. Accordingly, the 2002 mark-recapture experiment was conducted during September to maximize captures and to ensure mixing of marked and unmarked fish.

Information from this mark-recapture experiment was used to provide recommendations (such as adjustments to species stocking densities and lifestage) for the stocking strategy of Quartz Lake. The eventual goal will be to develop a management plan and stocking strategy for Quartz Lake to preserve fishing opportunity for rainbow trout, landlocked salmon, and Arctic char.

OBJECTIVES FOR 2002

The objectives for 2002 Quartz Lake mark-recapture studies were:

1) estimate the abundance of age-2 and older rainbow trout in Quartz Lake;
2) estimate the abundance of age-2 rainbow trout in Quartz Lake; and,
3) estimate the abundance of age-2 rainbow trout in Quartz Lake from the 2001 release.

METHODS

A two-sample mark-recapture experiment was conducted to estimate the abundance of age-2 and older rainbow trout in Quartz Lake. The age-2 cohort of fish was stocked during the summers 2000 and 2001, and fish either spent one or two winters in the lake. The experiment was completed during mid-September to reduce stress to the fish and avoid lower catch rates associated with warm water temperatures of mid-summer. Sampling protocols were identical to those described for 2001, with the exception that no hoop traps were used during 2002. Fish were given an upper caudal fin clip during the marking event, while fish handled during the recapture event received a lower caudal fin clip. Fish were also marked during the first event with injectable photonic dyes (New West Technologies, Santa Rosa, CA), using a BMX1000 SuperMICRO-Ject ™ tagging gun and fluorescent dyes to allow investigators to identify quadrant of origin for each fish, upon recapture. Such marking involved injecting dye with air-pressurized tagging guns into subcutaneous fin ray interstitial spaces at the base of either the right (RV) or left (LV) ventral fin. A small fine, colored line on the ventral fin enabled investigators to identify marked fish. Lake sampling areas were divided into four quadrants (as followed during 2001 studies; see Figure 4), and fish were fin-clipped according to location of capture during the first event. Fish marked in quadrants I and II received LV clips, while fish marked in quadrants III and IV received RV clips. Similarly, fish marked in quadrants I and IV received green photonic tags, while fish marked in quadrants II and III received red photonic tags (Table 7). There was no differential marking between gear types. During Event 2, fish were given a lower caudal fin clip regardless of where they were captured. Fish captured multiple times during either event were recorded, but not given additional marks.

Table 7.-Marks given to rainbow trout by location (Quadrant) of capture during mark-recapture studies in Quartz Lake, 2002 (LV is a left ventral fin tagged, while RV is a right ventral fin tagged).

Photonic	Fin Clip[a]	
Tag Color	LV	RV
Green	I	IV
Red	II	III

[a]LV = left ventral fin clip; RV = right ventral fin clip

For this study, we were interested in estimating the number of fish age-2 and older. Therefore, we did not need estimate the size composition of the population. A length frequency distribution normally allows investigators to identify age-2 fish from older and younger fish. Because the 16,669 catchable-sized rainbow trout stocked during 2002 may have been similar in size to age-2 and older fish already in the lake (7,837 catchables stocked in 2001 and $\approx$1,600 age-1 fish in the lake during spring 2001) 3,168 fish or 19% of newly stocked fish were marked with an adipose fin clip. With sufficient sample sizes, this enabled us to estimate the proportion of fish stocked during 2001 in the overall 2002 abundance of age-2 and older fish. With this information, fishery managers can determine if the number of newly stocked catchable-sized rainbow trout was adequate to sustain the sport fishing opportunity and harvest.

Mark-recapture data analysis followed those outlined for 2001 mark-recapture studies, using equations (1) and (2) to estimate abundance and associated variance as described in Objectives 1 and 2. In order to estimate the abundance of age-2 fish stocked as age-1 during 2001, as described in Objective 3, the equations from Bernard and Clark (1996) were utilized. For this application, the following simplified equation for one stratum was used:

$$\hat{r}_{ij} = \hat{N}_i \left(\frac{m_{ij}}{\lambda_i n_i} \right) \theta_j^{-1}, \qquad (3)$$

where: $\hat{r}_{ij}$ = the estimated number of fish from cohort j to population i;

m_{ij} = marks from cohort j recovered when sampling population i;

n_i = number of fish inspected for marks from population i;

λ = detection rate for marked fish (1 for this application) ;

$\hat{N}$ = estimated abundance of population i; and,

θ_j = probability of fish from cohort j having a mark.

Sampling variance is estimated using:

$$V(\hat{r}_{ij}) = \hat{r}_{ij}^{\,2}[G(\hat{p}_{ij}) + G(\hat{N}_{ij}) - G(\hat{p}_{ij})G(\hat{p}_{ij})], \qquad (4)$$

where:

$$G(\hat{p}_{ij}) = \frac{(1-\lambda_i\hat{\phi}_i\theta_j)}{m_{ij}}; \tag{5}$$

$$\hat{\phi}_i = \frac{n_i}{\hat{N}_i}; \text{ and,} \tag{6}$$

$$G(\hat{N}_i) = V(\hat{N}_i)\big/\hat{N}_i^2 \, . \tag{7}$$

RESULTS

During Event 1 (9 to 13 September, 2002), 253 rainbow trout 140 mm FL or greater were captured, marked, and released. During Event 2 (23 to 27 September, 2002), 364 rainbow trout were captured, eight of which were marked during Event 1. Overall, 586 unique rainbow trout ≥ 140 mm FL were handled during the experiment. Fish handled during the experiment ranged in size from 140 to 550 mm FL (≈5 inches to 22 inches), and averaged 298 mm FL. Investigators did not measure fish less than 100 mm FL, which would have included newly stocked age-0 fingerlings (from 2002). Distributions of fish lengths revealed a lack of modal distinction between what could be identified as age-1 and age-2 fish (Figure 11). The average size of fingerling rainbow trout prior to the experiment in 2002 was ≈49 mm FL. Based on observation of length distributions from the 2001 mark-recapture experiment, and historic data from 1991, age-1 fish (stocked as age-0 fingerlings in 2001) should have been approximately 150 to 200 mm FL. In addition, catchable fish stocked during summer 2002 (as age-1 catchables, since they spent 1 year in the hatchery prior to being stocked and began their summer as age-2) were discerned by adipose fin clips ($n = 67$). They ranged in size from 197 to 360 mm FL, and averaged 277 mm FL. Therefore, all fish under 200 mm FL were omitted from abundance estimation procedures, and all fish ≥ 200 mm FL were considered age-2 or older.

For fish ≥ 200 mm FL, 241 were marked during Event 1, while 348 were examined for marks during Event 2, with eight fish being recaptured. The number of unique fish age-2 and older was 581. Results from K-S tests indicated that there was no size selectivity between during sampling in either Event 1 or Event 2 ($D = 0.31$ $P = 0.44$ for marked vs. recaptured fish; $D = 0.06$, $P = 0.64$ for marked vs. examined fish). However, plots of the CDF's suggested that recaptured fish were smaller than marked or captured fish (Figure 12). Because so few fish were recaptured ($n = 8$), the apparent differences in the plots may have been misleading. Because no statistical differences were observed, we assumed there was no size selectivity in the experiment.

In this particular experiment, fish were not marked based on location of fyke net, i.e., offshore set vs. nearshore set, as during the experiment in 2001. However, fish were marked according to capture gear (Table 8). During Event 1, 74% of the fish were captured in fyke nets having center leads, while the remaining 26% were captured with typical fyke net sets. No fish were captured with tangle nets during Event 1. During Event 2, 43% were captured in fyke nets having center leads, 41% in typical fyke net sets, and 16% in tangle nets. Overall, eight fish were recaptured; four fish were recaptured in fyke nets, three fish were recaptured in fyke nets having center leads, and one fish was recaptured in a tangle net.

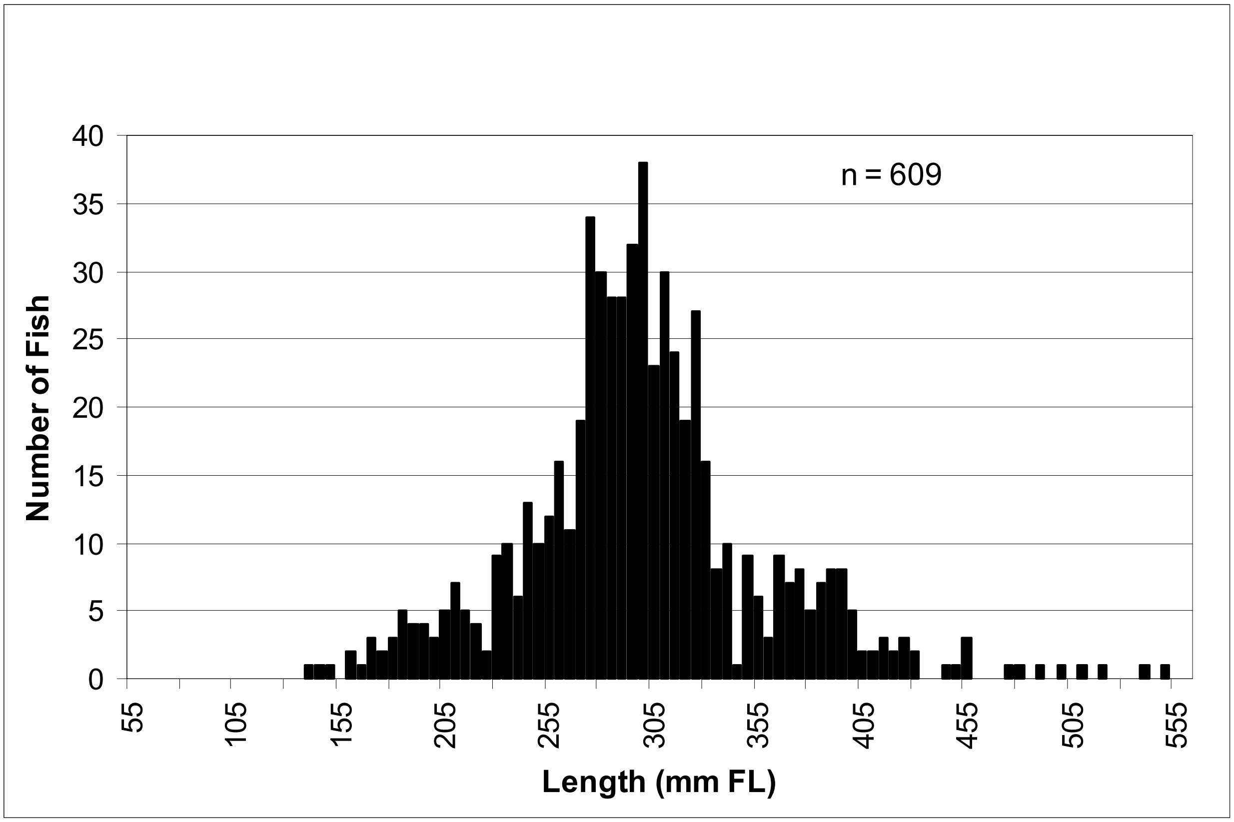


Figure 11.-Lengths of rainbow trout (≥ 140 mm FL) handled during the Quartz Lake mark-recapture experiment of 2002.

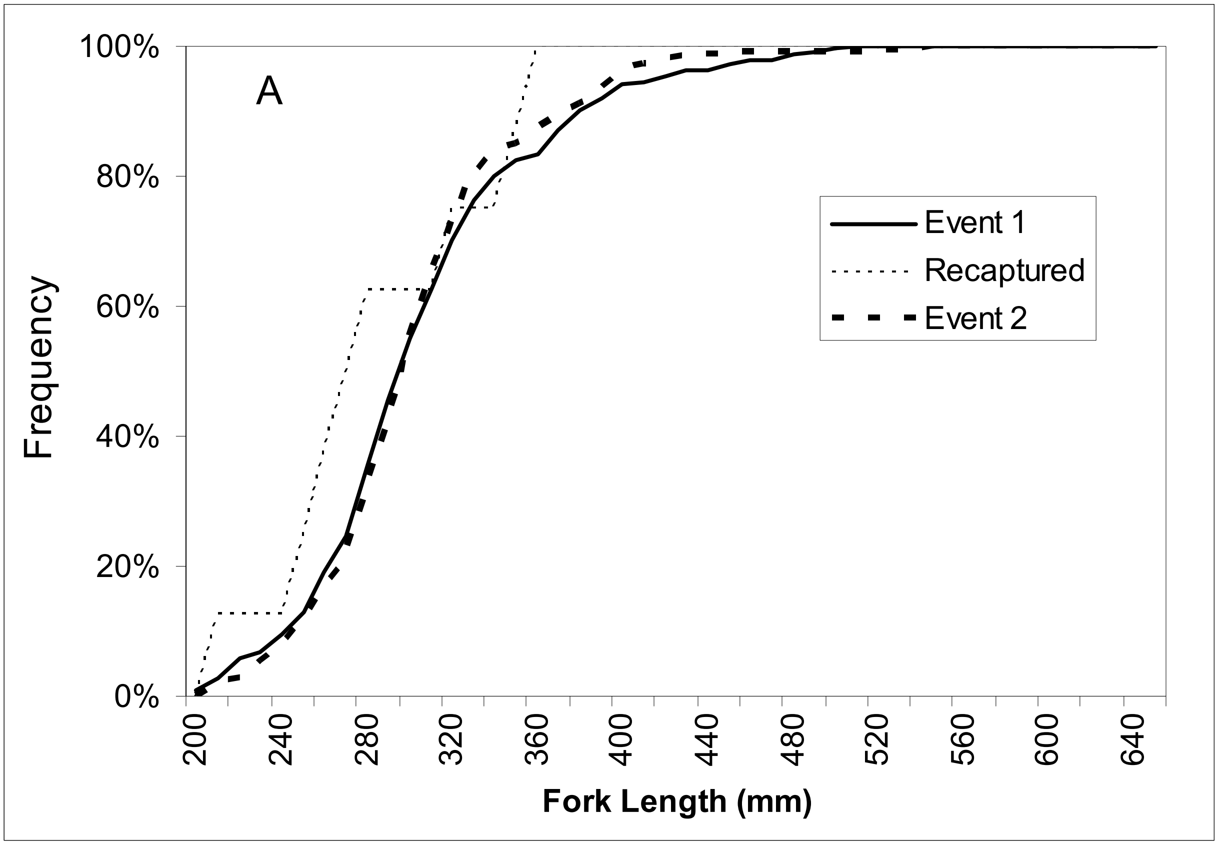


Figure 12.-Cumulative distribution function of lengths from rainbow trout (≥ 200 mm FL) captured during the mark-recapture experiment at Quartz Lake, 2002 (D = 0.31, P = 0.360 for marked fish vs. recaptured fish; D = 0.06, P = 0.64 for marked vs. examined fish).

Table 8.-Summary of rainbow trout captures (≥ 200 mm FL) by gear type during Quartz Lake mark-recapture studies, 2002.

	Fyke Net with Center lead	Fyke Net	Tangle Net	Total
Event 1 (marked)	179	62	0	241
Event 2 (examined)	150	143	57	348
Recaptures	3	4	1	8
m_2:n_2	0.02	0.03	0.02	----

Fish were differentially marked according to location of first capture in the lake (Table 7), and the number of fish marked, examined and recaptured by quadrant location during the experiment was summarized (Table 9). Recapture rates and capture probabilities by quadrant were examined using contingency table analysis, and were not significantly different between quadrants (Table 10).

Of the eight fish recaptured during the experiment, five fish moved to different quadrants between events (Table 11). Although the sample size was small, this information provided evidence to suggest that marked fish mixed between events. Catches of fish in each particular net also varied by day, and were particularly dependent on weather events. For example, if strong prevailing winds were blowing from the southeast on any particular day, catches of fish in nets on the north end of the lake were usually greatest the following day, while those on the south side of the lake were typically much smaller, or even zero. If winds shifted direction, catches also seemed to change correspondingly.

The estimated abundance of age-2 and older rainbow trout (≥ 200 mm FL) was 9,383 fish (SE = 2,874). The abundance estimate was not stratified by size or by gear type. The estimated contribution ($\hat{r}$) of rainbow trout from 2001 (stocked as age-1 catchables during 2001) was 202 fish (SE = 91; see Appendix F for input variables and intermediate values). This estimate is approximately 2% of the number of fish released as catchables into Quartz Lake during 2001. The remaining 98% of the fish stocked were apparently harvested during 2001-2002. The equations of Bernard and Clark (1996) were also used to estimate the contribution of fish stocked during 2002 (from a known proportion having adipose fin clips) at 5,659 fish (SE = 1,852; using the same intermediate values shown in Appendix F, but using 67 for $m(ij)$ as an input variable for the number of fish with adipose fin clips handled during both events).

DISCUSSION

Data from the 2002 population assessment support the hypothesis that most captured rainbow trout > 200 mm FL (and available to anglers) originated from catchable rainbow trout stocked during 2002. Indeed, the estimated contribution ($\hat{r} = 202$) of catchables stocked during 2001 suggests that nearly all such fish (98%) were harvested during 2001-2002. Although age-1 rainbow trout are present (from age-0 fingerlings), results from 2001 indicate that too few age-1 fish currently reach catchable size to support the fishery. The fishery is currently sustained by

Table 9.-Summary of marked, unmarked, and recaptured rainbow trout (≥ 200 mm FL) by quadrant location during Quartz Lake mark-recapture studies, 2002.

Recaptured	Marked Quadrant					
Quadrant	I	II	III	IV	Unmarked	Totals
I	0	0	0	0	88	88
II	0	0	2	0	64	66
III	1	0	2	2	155	160
IV	0	0	0	1	35	36
Not Recaptured	20	79	66	68		
Totals	21	79	70	71		

Table 10.-Contingency table analyses of recapture rates and capture probability by location of capture of rainbow trout (≥ 200 mm FL) in Quartz Lake, 2002.

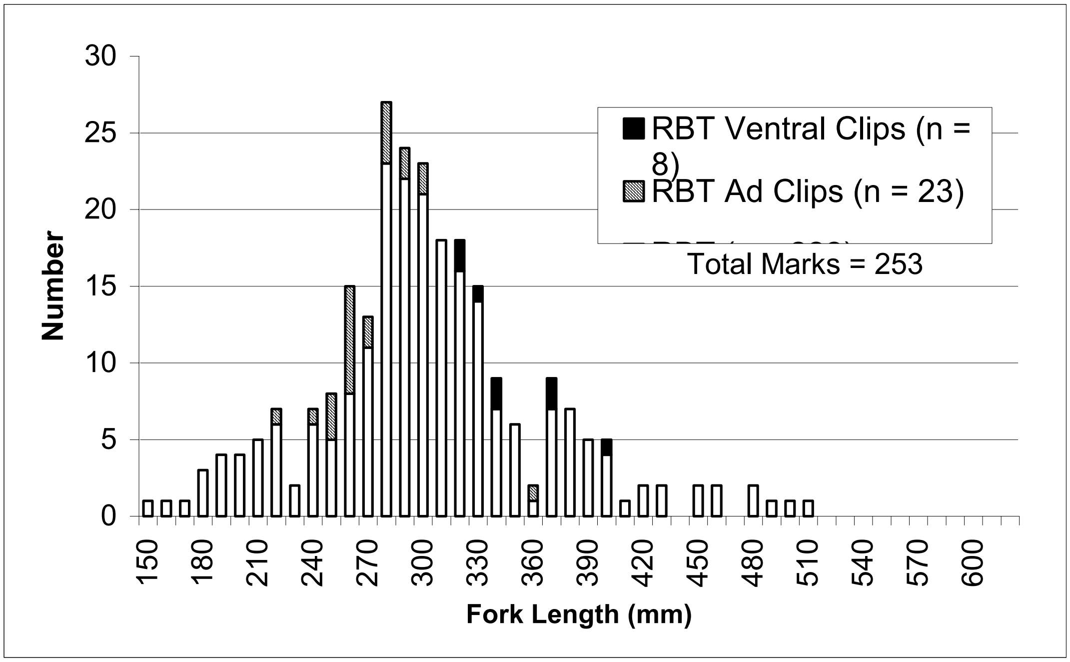
Quadrant	Marked	Recaptured in Lake	m_2:n_1	Examined	Recaptures	m_2:n2
I	21	1	0.05	88	0	0.0
II	79	0	0.0	66	2	0.03
III	70	4	0.06	160	5	0.03
IV	71	3	0.04	36	1	0.03
Totals	241	8		350	8	
χ^2	*4.28*			*2.77*		
Df	*3*			*3*		
P	*0.23*			*0.43*		

Table 11.-Summary of quadrant location for individually marked and recaptured rainbow trout ≥ 200 mm FL (n = 8) handled during Quartz Lake mark-recapture studies, 2002 (italics and arrow denotes movement between quadrants).

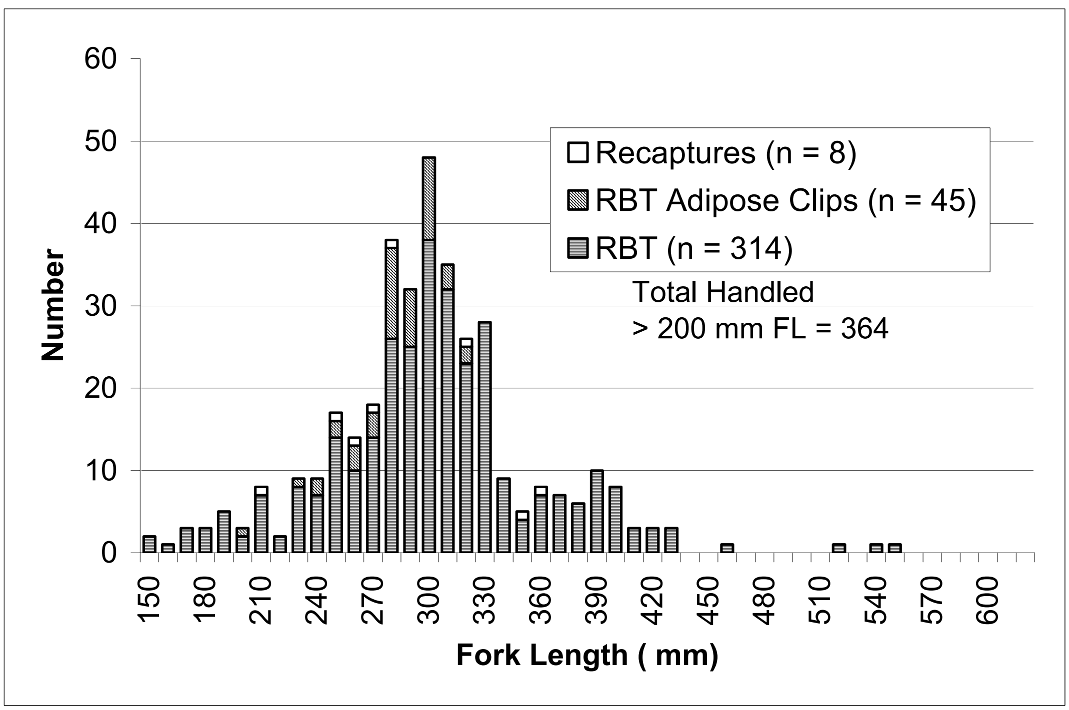
Quadrant Marked (Event1)	Quadrant Recaptured (Event 2)
IV →	*III*
III	III
III	III
IV →	*III*
I →	*III*
III →	*II*
III →	*II*
IV	IV

management actions, whereby catchable-sized rainbow trout are reallocated to Quartz Lake from other stocking locations. Specifically, 16,669 catchable rainbow trout were introduced into Quartz Lake during summer 2002, and these particular fish are most abundant in the catches of the 2002 mark-recapture experiment as indicated by the relatively large number of fish captured with adipose fin clips (Figures 13 and 14).

If landlocked salmon and Arctic char are the main predator of fingerling rainbow trout in Quartz Lake, then a possible solution to increase the survival of fingerling rainbow trout is to reduce the number of salmon and char in the lake. Fishery managers have progressively reduced coho salmon stocking in Quartz Lake by nearly 50% since 1993 (Appendix E), and chinook salmon have not been stocked since 2000. In 2002, no landlocked salmon were stocked into Quartz Lake. Completely eliminating landlocked salmon from Quartz Lake is not preferred, however, because coho salmon make up a large portion of the winter fishery catch and harvest (F. Parker, Alaska Department of Fish and Game, Delta Junction, personal communication). Current plans are to reduce fingerling coho salmon stocking to 30,000 (from 150,000) fish annually. This approach may lessen competition and potential predation of rainbow trout fingerlings, yet still preserve landlocked salmon fishing opportunity, particularly during the winter ice fishery. Chinook salmon catchables have been stocked into Quartz Lake twice during the past ten years. Staff may resume stocking chinook salmon catchables if anglers desire increased landlocked salmon fishing opportunities, since they provide an immediate contribution to the fishery. Anglers also value catching Arctic char in Quartz Lake. Fishery managers plan to continue stocking subcatchable Arctic char at intermediate levels. If, in the future, more catchable char become available from the hatchery, staff may switch to stocking this size of fish, but at lower densities. These combined actions may serve to lower potential predation on rainbow trout fingerlings. However, if large rainbow trout are also a major predator on stocked rainbow trout



a)



b)

Figure 13.-Lengths of rainbow trout captured during Event 1 (Marking Event) in Quartz Lake, 2002 (a); Lengths of rainbow trout captured during Event 2 (Recapture Event) with recaptures (n = 8) shown (b).

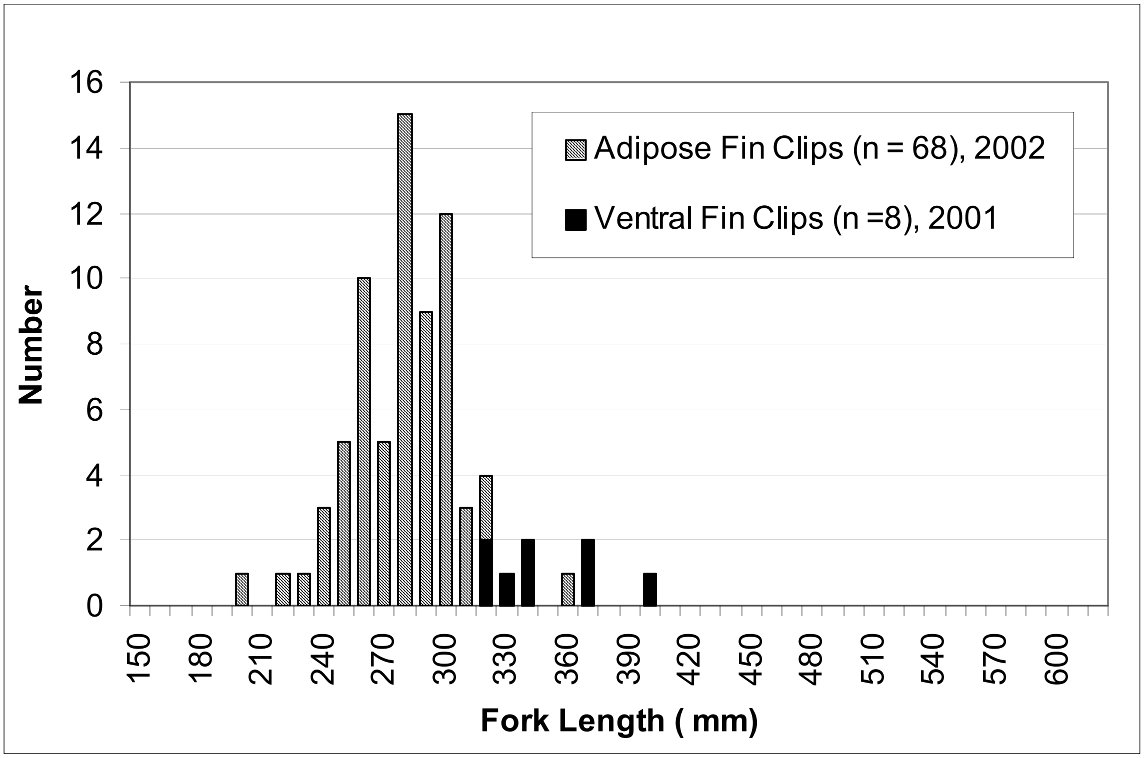


Figure 14.-Lengths of rainbow trout with adipose and ventral fin clips captured during the mark-recapture experiment in Quartz Lake, 2002 (fish with adipose fin clips stocked during 2002, while fish with ventral fin clips stocked during 2001).

fingerlings, then eliminating or reducing the number of landlocked salmon and char may not have the desired result of reducing predation.

During 2001 and 2002, over 300,000 rainbow trout fingerlings each year were stocked into Quartz Lake. In addition, 7,837 catchable rainbow trout during 2001, and 16,669 catchables during 2002 were stocked into Quartz Lake (Appendix D). Fish of this size (≈6 to 8 inches) should exhibit greater survival than age-0 fingerlings, and make immediate contribution to the creel. Additionally, juvenile rainbow trout (≈52,600 fish < 1 inch in length) were reared in small, productive ponds in the Delta Junction area during 2002, and were later removed and restocked (≈12,000 fish) at subcatchable sizes (≈3 inches in length) into Quartz Lake. Pond rearing and subsequent restocking into Quartz Lake as subcatchable-sized fish will continue in 2003, and perhaps during future years. Such a stocking strategy may ensure multiple age classes of rainbow trout will exist in Quartz Lake, and may eventually increase the number of fish available to anglers. During 2003, age-0 fingerling rainbow trout will continue to be stocked into Quartz Lake, but at reduced densities (≈50%). The remaining fingerlings will be pond-reared as described above, to increase their size prior to being stocked into Quartz Lake.

In the near future, a portion of potential rainbow trout fingerling predators will have been reduced, and multiple age classes of rainbow trout will have been stocked. Investigators believe that annual introductions of subcatchable-sized rainbow trout (20 to 40 gram and ≈4 to 6 inches long) early in a given growing season will ultimately restore the fishery at Quartz Lake. Fish at this particular lifestage were historically stocked in the early 1990s (Appendix E). Figure 15 depicts all unique rainbow trout handled during Quartz Lake mark-recapture experiments in 1991 and 2002. Subcatchables were stocked prior to mark-recapture studies in 1991, as well as during 1990. Both cohorts are discernable in the bimodal distribution of the 1991 data (in this case, as age-1 and age-2 fish that came from subcatchable introductions). The distribution from 2002 is from age-1 and age-2 fish, both cohorts being stocked during 2001 or 2002 as age-1 catchables. Most catchables stocked during 2001 have apparently been harvested, since those fish (≥ 310 mm FL) are relatively few in number, as confirmed by so few (n = 8) ventral fin clips being recovered during 2002, and their estimated contribution being only 2%. Also confirming this assertion is the observation that the estimated harvest of rainbow trout from Quartz Lake (20,418 trout during 2000 and 2001 combined; Walker et al. 2003 and Jennings, et. al. *In prep*) closely matches the number of stocked catchables rainbow trout during the past two years (≈24,500). In addition, 16,669 catchable rainbow trout were stocked during summer of 2002, but the estimated abundance of rainbow trout (≥ 200 mm FL) was only 9,383 fish. If rainbow trout fingerling survival continues to be low, then age-1 and age-2 fish can only come from catchable-sized fish introductions. In Figure 15, there is also no detectable mode in the size 2002 size distribution data representing age-3 fish. Figure 16, depicting rainbow trout from both 2001 and 2002 mark-recapture experiments also fails to show a mode representing age-3 fish. The peak mode at 305 mm FL likely represents age-1 and age-2 fish stocked as catchables during both 2001 and 2002. It is unclear if fish ranging in size from ~355 mm FL to 405 mm FL represent age-3. When compared to 1991 data, fish in this particular size range could be age-2 as well. Age-1 fish (from age-0 introductions) are also present in the lake, but were not measured during 2002 and are not represented in the 2002 data in Figure 16. Noteworthy is the dramatic difference in fishing effort during mark-recapture studies of 1991 and 2002. In 1991, six fyke nets with center leads were utilized to capture fish. In 2002, four fyke nets with center leads, eight additional fyke nets, and two gillnets were employed to capture fish. Overall, 2,113 fish were

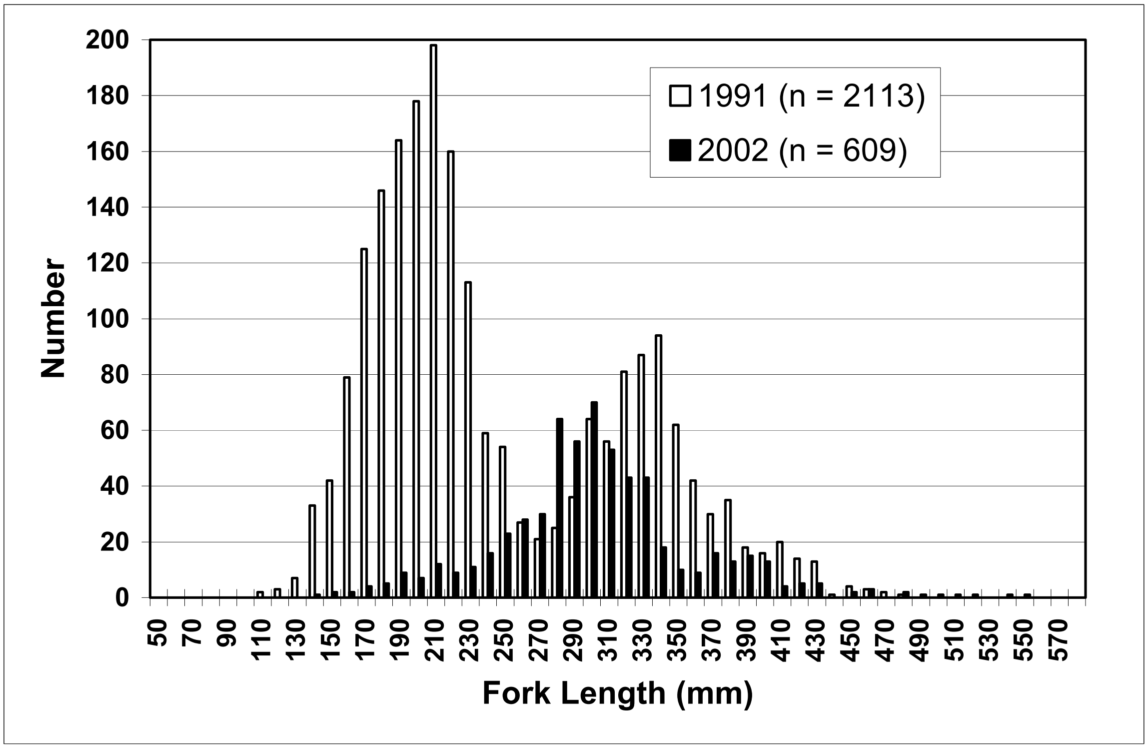


Figure 15.-Lengths of Quartz Lake rainbow trout captured during mark-recapture experiments during 1991 and 2002.

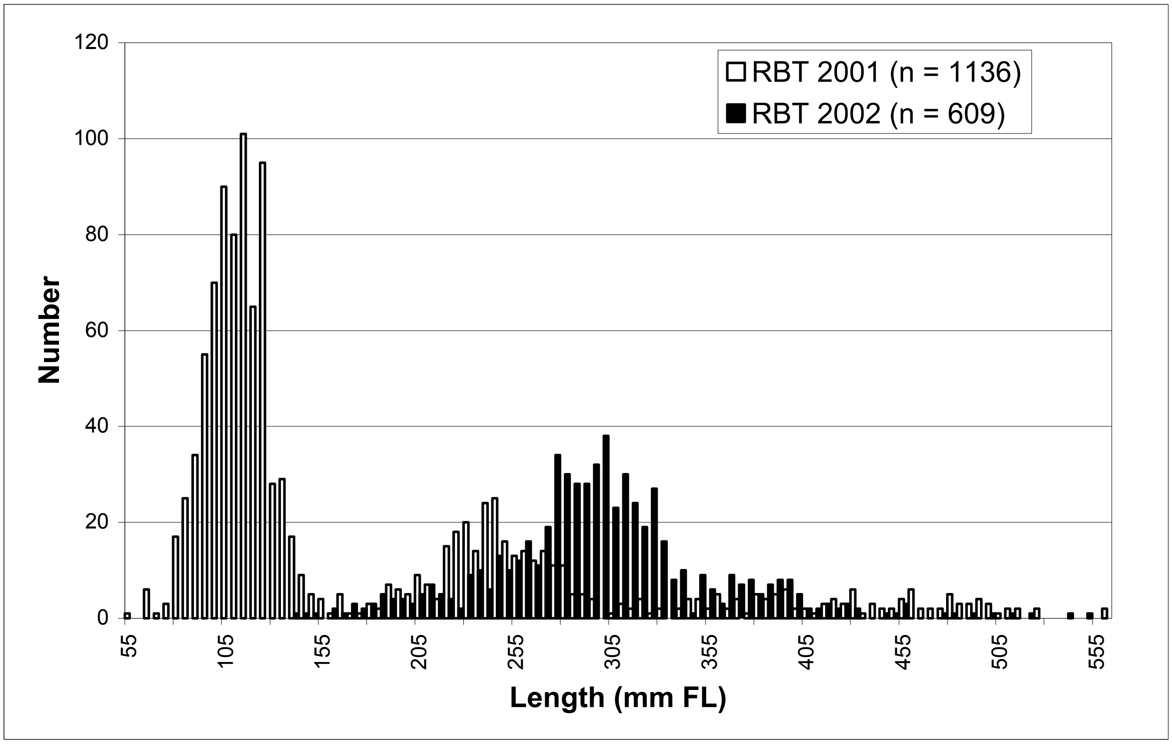


Figure 16.-Lengths of Quartz Lake rainbow trout captured during mark-recapture experiments during 2001 and 2002.

handled during 1991, while only 583 were handled during 2002, with twice as much fishing effort utilized as in 1991. This evidence further suggests that catchables stocked during 2001 were indeed harvested. Combined with poor fingerling survival observed from mark-recapture results of 2001, our data suggests that catchable rainbow trout are the stocking product that is currently sustaining the rainbow trout fishery in Quartz Lake. However, since stocking catchables is currently only possible by reallocating fish from other locations, sport fishing opportunity is lost from fisheries elsewhere in the region.

In 2001 and 2002, staff reallocated catchable rainbow trout, originally destined for Piledriver Slough and other small lakes, into Quartz Lake. This measure was also repeated during 2002, with additional fish being reallocated from elsewhere. This stocking strategy, however, cannot continue without fisheries elsewhere being impacted. Ideally, fishery managers could switch from stocking fingerling rainbow trout to stocking solely catchable-sized fish. However, this option is currently not available, as hatchery production cannot expand with existing facilities. Growing fingerling-sized fish to large sizes is possible in Quartz Lake, and fingerlings are much less expensive to produce than catchable-sized fish. The latter are reared for at least a year and have additional feed and space requirements. However, if fingerling survival is poor, their return to the creel may be very low. Doxey (1992) concluded that rainbow trout reared to subcatchable size can be a cost effective substitute for fingerling stockings. We recommend that a portion of hatchery production be dedicated to producing subcatchable rainbow trout specifically for annual stocking into Quartz Lake. The production of catchable-sized fish at both hatcheries is currently dependant on availability of heated water. In the past, subcatchable production was accomplished by raising fingerlings (for an extra nine to 10 months) in unheated outdoor raceways. This practice was terminated in 1999. With increased Arctic char production, hatchery production space is also currently limited. However, with near-future production improvements (such as utilizing indoor circular raceways), more space may become available and the production of subcatchable rainbow trout may be resumed. If hatchery production is not possible, another option is to rear rainbow trout fingerlings in net pens within Quartz Lake, in order to grow fish to larger sizes before stocking. Viavant (1992) has shown that it is logistically and economically feasible to grow rainbow trout in net pens to near-catchable size prior to stocking. This option should remain viable for staff, particularly if catchable fish production capacities will remain limited at the hatcheries.

The angling public has approached the Sport Fish Division with requests that bag limit changes be adopted for Quartz Lake rainbow trout. Specifically, these requests focus on preserving sport fishing opportunity, particularly for large rainbow trout (18 inches or greater), by reducing the bag limit from 30 to 10 fish of any species or less, with only one being over 18 inches in length. Such proposed regulation changes will be presented to the Board of Fisheries in 2004. It is unclear whether large rainbow trout (18 inches or greater) have been more numerous in the past than they are now. However, it is clear that future recruitment will be low if fingerling survival continues to low, and no modifications to the stocking strategy are made. Based on the results from 2001 and 2002, investigators make the following recommendations:

1) reduce potential predation on newly-stocked rainbow fingerlings by reducing the number of stocked predators, while still preserving fishing opportunity for larger rainbow trout, landlocked salmon, and Arctic char;

2) continue stocking fingerling rainbow trout, but at half the densities (150,000 annually);

3) stock 30,000 subcatchable-sized rainbow trout annually early in the growing season (late May or early June);
4) pond-rear or net pen-rear rainbow trout (150,000) to subcatchable size if hatchery production is not available (150,000 fed fry may potentially yield 30,000 subcatchable rainbow trout); and,
5) continue monitoring the rainbow trout population with mark-recapture or test-netting studies.

ACKNOWLEDGMENTS

April Behr, Larry Boyle, Holly Carroll, Julie Kietzman, Anne Peniston, Dan Reed, Don Roach Shannon Spring, and Lisa Stuby assisted with the field work. Special thanks are extended to Henry Garbowski and his family, as well as to Gary Lorenzen and family, for use of their cabins and property on Quartz Lake. Sara Case provided editorial and formatting assistance. The U.S. Fish and Wildlife Service provided partial funding for this study through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-16 and F-10-17, Job No. E-3-1(a).

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APPENDIX A

Appendix A.-Assumptions necessary for accurate estimation of abundance in a closed population.

The assumptions necessary for accurate estimation of abundance in a closed population were as follows (taken from Seber 1982):

1. the population was closed (no change in the number of rainbow trout in the population during the estimation experiment; i.e., there was no immigration, emigration, births or deaths);
2. all rainbow trout have the same probability of capture in the marking sample or in the recapture sample, or marked and unmarked rainbow trout mix completely between marking and recapture events;
3. marking rainbow trout does not affect their probability of capture in the recapture sample;
4. rainbow trout do not lose their mark between the marking and recapture events; and,
5. all marked rainbow trout were reported when recovered in the recapture sample.

For assumption 1, no immigration or emigration was assured because the lakes do not have inlets or outlets. The second half of assumption 1 was also assured because rainbow trout do not reproduce in these lakes. If during the study the probability of mortality was equal for marked and unmarked fish then the abundance estimate was germane to the first event. To minimize the likelihood of higher mortality rates for marked fish, all captured fish were handled carefully and any fish that showed signs of severe stress was marked by excising a small portion of a fin that was not used to identify capture method prior to release. Any fish given such a mark was not considered part of the mark-recapture experiment. A hiatus of at least ten days should have been sufficiently long to minimize the effect of previous capture on capture probability as related to assumption 3. Validity of assumptions 2 and 3, relative to sampling induced selectivity of fish, was tested with either Kolmogorov-Smirnov (K-S) or Chi-squared (contingency table) tests generated from length data collected during the marking and recapture events (Appendix C). A length frequency histogram was used to distinguish size classes.

-continued-

The first hypothesis tested if probability of a rainbow trout being captured during the second event was independent of the size of the trout. Probability of capture usually differs by the size of rainbow trout, especially when a size selective gear was used. Fyke nets should not be size selective, however, they were typically placed near shore in shallow water where part of the population may not frequent. Given this situation the probability of capture will not be the same for all fish. If this test was significant, the recapture sample was biased and the data were partitioned into size classes. Population estimates were generated for each size class and these independent estimates were summed to estimate the abundance of the entire population. If the test did not detect a significant difference, the data were not partitioned and a single population estimate sufficed.

The second hypothesis tested if probability of a rainbow trout being captured during the first event was independent of the size of the trout. There were four possible outcomes of these two tests; either one or both of the samples were biased or neither were biased. Possible actions for data analysis were outlined in Appendix C.

Assumption 4 was assured because there was not sufficient time for excised tissue to grow back.

Assumption 5 was assured because of rigorous examination of all fish for fin clips.

Complete mixing of marked and unmarked rainbow trout between the first and second events was assumed to occur during the experiment. To promote mixing and give each fish an equal chance of being captured there was a hiatus of at least 10 days between the first and second events, and fish handled during all events were released toward the middle of the lake.

APPENDIX B

Appendix B.-Methodologies for alleviating bias due to gear selectivity by means of statistical inference.

	Result of first K-S (or χ^2) test[a]	Result of second K-S (or χ^2) test[b]
Case I[c]		
	Fail to reject H_o	Fail to reject H_o
	Inferred cause: There was no size-selectivity during either sampling event.	
Case II[d]		
	Fail to reject H_o	Reject H_o
	Inferred cause: There was no size-selectivity during the second sampling event, but there was during the first sampling event.	
Case III[e]		
	Reject H_o	Fail to reject H_o
	Inferred cause: There was size-selectivity during both sampling events.	
Case IV[f]		
	Reject H_o	Reject H_o
	Inferred cause: There was size-selectivity during the second sampling event; the status of size-selectivity during the first event was unknown.	

[a] The first χ^2 test was based on a contingency table to examine the effect of variable catchability of marked fish captured during the second event for various size/age categories. The contingency table was made up of marked fish from the first event that were re-captured and not re-captured in the second event. H_o for this test was: The probability of capture in the second event for marked fish was constant across the various categories.

or

The first K-S (Kolmogorov-Smirnov) test was on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_o for this test was: The distribution of lengths of fish sampled during the first event was the same as the distribution of lengths of fish recaptured during the second event.

[b] The second χ^2 test was based on a contingency table to examine the effect of variable catchability in the first event for given size/age categories. The contingency table was made up of marked and unmarked fish captured in the second event. H_o for this test was: The probability of capture in the first event was constant across the various categories.

or

The second K-S test was on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_o for this test was: The distribution of lengths of fish sampled during the first event was the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling events for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Also calculate a single abundance estimate without stratification.

If stratified and unstratified estimates were dissimilar, discard unstratified estimate and use lengths and ages from second event and adjust these estimates for differential capture probabilities.

If stratified and unstratified estimates were similar, discard estimate with largest variance. Use lengths and ages from first sampling event to directly estimate size and age compositions.

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Testing of assumptions necessary for accurate abundance estimation may also reveal biases in age and size composition samples. Because age and length information were collected during mark-recapture sampling, bias in mark-recapture samples also indicates bias in age and size data that were collected. Age and size composition were used to apportion the population estimate into age classes or size categories, so that age and length information collected during either the marking sample, the recapture sample, or both samples may be used to calculate age and size composition.

If case I was indicated by tests (Appendix B), no adjustments to age and size data were necessary and data from both events may be pooled. If case II occurs, age and size data from the second event must be used to estimate age and size composition proportions. If the population was closed between sampling events the abundance estimate was germane to both sampling events. For these two scenarios the proportion of fish at age was calculated as:

$$\hat{p}_i = \frac{y_i}{n} \tag{1}$$

where: $\hat{p}_i =$ the proportion of rainbow trout that were age *i*; y_i = the number of rainbow trout sampled that were age *i*; and, n = the total number of rainbow trout sampled.

The unbiased variance of this proportion was estimated as:

$$\hat{V}[\hat{p}_i] = \frac{\hat{p}_i(1-\hat{p}_i)}{n-1} \tag{2}$$

Size composition was estimated in a similar manner, replacing age class with the two size categories (less than 355 mm and 355 mm or larger).

If case III or case IV from inference testing occurs, either the first and second events were biased or the second event was unbiased and the status of the first event was unknown. If case III occurs, age and size data from both events can be pooled and adjustments made to these data. If case IV occurs and the partitioned and un-partitioned abundance estimates were dissimilar, age and size data from the second event must be used to estimate compositions. These data must also be adjusted for bias due to size-selectivity. To adjust age and size data, the proportion of fish at age was calculated by summing independent abundances for each age or size class and then dividing by the summed abundances for all age or size classes. First the conditional proportions from the sample were calculated:

$$\hat{p}_{ji} = {n_{ji}}/{n_j} \tag{3}$$

where: n_j = the number sampled from size class *j* in the mark-recapture experiment; n_{ji} = the number sampled from size class *j* that were age *i*; and, $\hat{p}_{ji}$ = the estimated proportion of age *i* fish in size class *j*. The variance calculation for $\hat{p}_{ji}$ was identical to equation 6 (with appropriate substitutions).

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The estimated abundance of age *i* fish in the population was then:

$$\hat{N}_i = \sum_{j=1}^{s} \hat{p}_{ji} \hat{N}_j \qquad (4)$$

where: N_i = the estimated abundance in size class *j* and s = the number of size classes.

The variance for $\hat{N}_i$ in this case was approximated by (Goodman 1960):

$$\hat{V}\left[\hat{N}_i\right] = \sum_{j=1}^{s} \left(\hat{V}\left[\hat{p}_{ji}\right] \hat{N}_j^2 + V\left[\hat{N}_j\right] \hat{p}_{ji}^2 - \hat{V}\left[\hat{p}_{ji}\right] V\left[\hat{N}_j\right] \right) \qquad (5)$$

The estimated proportion of the population that were age *i* $(\hat{p}_i)$ was then:

$$\hat{p}_i = \hat{N}_i \big/ \hat{N} \qquad (6)$$

where: $\hat{N} = \sum_{j=1}^{s} \hat{N}_j$

Variance of the estimated proportion can be approximated with the delta method (Seber 1982):

$$\hat{V}\left[\hat{p}_i\right] \approx \sum_{j=1}^{s} \left\{ \left(\frac{\hat{N}_j}{\hat{N}} \right)^2 \hat{V}\left[\hat{p}_i\right] \right\} + \frac{\sum_{j=1}^{s} \left\{ V\left[\hat{N}_j\right] \left(\hat{p}_{ji} - \hat{p}_i \right)^2 \right\}}{\hat{N}^2} \qquad (7)$$

APPENDIX C

Appendix C.-Archive files for data collected during studies covered in this report.

File Name	Description
KS_MRData.xls	KS tests for mark-recapture experiment at Quartz Lake, 2001
QuartzLakeRBT.xls	Data from mark-recapture experiment at Quartz Lake, 2001
QuartzRBTAnalysis.xls	Data from mark-recapture experiment at Quartz Lake, 2001
Quartz Stocking Table.xls	Historical Data from stocking fish at Quartz Lake
Quartz_2002_MR.xls	Data from mark-recapture experiment at Quartz Lake, 2002
M to R.xls	Data from mark-recapture experiment at Quartz Lake, 2002
KS_MR2002_200.xls	Data from mark-recapture experiment at Quartz Lake, 2002
DataSheets.xls	Data from mark-recapture experiment at Quartz Lake, 2002
BernardClarkTab2.xls	Data from mark-recapture experiment at Quartz Lake, 2002
Adclips.xls	Data from mark-recapture experiment at Quartz Lake, 2002
Historic_1991.xls	Data from mark-recapture experiment at Quartz Lake, 1991

Data files are available from the Alaska Department of Fish and Game, Sport Fish Division, 1300 College Rd, Fairbanks, Alaska, 99701.

APPENDIX D

Appendix D.-Survival and variance calculations from 2000 to 2001 of fingerling rainbow trout stocked into Quartz Lake.

Survival ($\hat{S}$) was calculated as:

$$\hat{S} = \frac{\hat{N}_{age-1}}{N_{stocked\,2000}}$$

where,

$\hat{N}_{age-1}$ = estimated abundance of age-1 rainbow trout during spring 2001, and

$N_{stocked\,2000}$ = number of fingerling (age-0) rainbow trout stocked into Quartz Lake during 2000.

Survival was calculated to be:

$$\hat{S} = \frac{1{,}588_{age-1}}{352{,}731_{stocked\,2000}}$$

$$\hat{S} = 0.005\,.$$

Variance was calculated as:

$$V(\hat{S}) = \frac{V(\hat{N}_{age-1})}{(N_{stocked\,2000})^2}\,.$$

Variance was calculated to be:

$$V(\hat{S}) = \frac{32{,}361}{352{,}731^2}$$

$$V(\hat{S}) = 2.6^{-07}.$$

APPENDIX E

Appendix E.-Stocking history for Quartz Lake, 1971-2002.

Species	Stocking Date	Number Stocked	Age[a]	Sex[b]	Length (inches)	Brood Year
Rainbow trout	18-Jun-71	810,000	D	MF	1.2	71
Rainbow trout	23-Jun-72	59,900	F	MF	2.7	72
Rainbow trout	26-Jun-72	30,800	F	MF	2.6	72
Rainbow trout	14-Jul-72	62,000	F	MF	2.7	72
Rainbow trout	20-Jul-72	57,200	F	MF	2.9	72
Rainbow trout	24-Jul-72	47,700	F	MF	3.0	72
Rainbow trout	26-Jul-72	49,200	F	MF	3.0	72
Rainbow trout	1-Aug-73	64,300	F	MF	3.0	73
Rainbow trout	6-Aug-73	72,500	F	MF	3.1	73
Rainbow trout	13-Aug-73	69,300	F	MF	3.0	73
Rainbow trout	15-Aug-73	79,000	F	MF	3.1	73
Rainbow trout	10-Jul-74	39,700	F	MF	1.8	74
Rainbow trout	16-Aug-74	41,700	F	MF	2.7	74
Rainbow trout	20-Aug-74	41,200	F	MF	2.7	74
Rainbow trout	21-Aug-74	37,200	F	MF	2.8	74
Rainbow trout	22-Aug-74	16,800	F	MF	2.8	74
Rainbow trout	28-Aug-74	7,700	F	MF	2.9	74
Rainbow trout	24-Jul-75	68,000	F	MF	2.6	75
Rainbow trout	28-Jul-75	93,000	F	MF	2.5	75
Rainbow trout	29-Jul-75	48,900	F	MF	2.6	75
Rainbow trout	2-Aug-76	100,000	F	MF	1.7	76
Rainbow trout	24-Aug-76	7,900	F	MF	3.1	76
Rainbow trout	24-Aug-76	47,400	F	MF	2.3	76
Coho Salmon	23-Jun-77	143,000	F	MF	2.0	76
Rainbow trout	26-Jul-77	110,500	F	MF	2.2	77
Rainbow trout	11-Aug-77	3,301	S	MF	6.0	77
Coho Salmon	15-Aug-77	54,400	F	MF	2.6	76
Coho Salmon	15-Aug-78	4,600	F	MF	2.7	77
Coho Salmon	17-Aug-78	50,606	F	MF	2.8	77

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Species	Stocking Date	Number Stocked	Age[a]	Sex[b]	Length (inches)	Brood Year
Rainbow trout	13-Sep-79	32,858	F	MF	2.2	79
Coho Salmon	21-Sep-79	150,095	F	MF	3.7	78
Rainbow trout	28-Aug-80	87,559	F	MF	2.1	80
Coho Salmon	14-May-81	109,914	F	MF	2.0	80
Coho Salmon	19-May-81	39,400	F	MF	2.2	80
Rainbow trout	15-Sep-82	226,600	F	MF	2.1	82
Coho Salmon	23-May-83	46,543	F	MF	2.6	82
Rainbow trout	29-Aug-83	233,172	F	MF	2.1	83
Coho Salmon	24-May-84	6,000	F	MF	2.9	83
Coho Salmon	29-May-84	45,200	F	MF	3.0	83
Coho Salmon	30-May-84	15,150	F	MF	3.0	83
Coho Salmon	31-May-84	62,568	F	MF	2.3	83
Coho Salmon	12-Jun-84	26,800	F	MF	2.3	83
Rainbow trout	15-Aug-84	252,000	F	MF	2.4	84
Rainbow trout	21-Aug-84	21,567	F	MF	2.5	84
Coho Salmon	28-May-85	64,970	F	MF	2.8	84
Coho Salmon	29-May-85	65,706	F	MF	2.8	84
Coho Salmon	30-May-85	19,300	F	MF	2.9	84
Rainbow trout	15-Jul-85	100,000	F	MF	1.9	85
Rainbow trout	21-Aug-85	72,148	F	MF	2.5	85
Rainbow trout	23-Aug-85	74,361	F	MF	2.3	85
Rainbow trout	26-Aug-85	51,500	F	MF	2.2	85
Rainbow trout	27-Aug-85	21,720	F	MF	2.3	85
Rainbow trout	30-Aug-85	67,647	F	MF	2.3	85
Coho Salmon	31-May-86	57,557	F	MF	3.0	85
Coho Salmon	4-Jun-86	40,365	F	MF	2.9	85
Coho Salmon	4-Jun-86	40,365	F	MF	2.9	85
Coho Salmon	6-Jun-86	30,213	F	MF	2.9	85

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Species	Stocking Date	Number Stocked	Age[a]	Sex[b]	Length (inches)	Brood Year
Rainbow trout	15-Aug-86	107,198	F	MF	2.2	86
Rainbow trout	15-Aug-86	48,587	F	MF	2.2	86
Rainbow trout	18-Aug-86	84,546	F	MF	2.3	86
Rainbow trout	20-Aug-86	56,546	F	MF	2.2	86
Rainbow trout	22-Aug-86	27,988	F	MF	2.2	86
Rainbow trout	8-Oct-86	5,000	F	MF	2.2	86
Coho Salmon	29-Apr-87	38,342	F	MF	2.5	86
Coho Salmon	1-May-87	46,747	F	MF	2.4	86
Rainbow trout	27-May-87	10,000	S	MF	5.4	86
Coho Salmon	3-Jun-87	35,556	F	MF	3.2	86
Coho Salmon	4-Jun-87	47,844	F	MF	3.1	86
Rainbow trout	11-Aug-87	227,917	F	MF	2.5	87
Rainbow trout	26-Aug-87	101,795	F	MF	2.5	87
Rainbow trout	26-Aug-87	78,205	F	MF	2.4	87
Coho Salmon	25-May-88	65,597	F	MF	2.8	87
Coho Salmon	26-May-88	61,148	F	MF	2.8	87
Coho Salmon	26-May-88	23,255	F	MF	2.8	87
Rainbow trout	27-May-88	11,279	S	MF	5.2	87
Rainbow trout	27-May-88	12,944	S	MF	5.0	87
Rainbow trout	1-Jun-88	12,354	S	MF	5.3	87
Rainbow trout	2-Jun-88	11,517	S	MF	5.3	87
Rainbow trout	12-Aug-88	150,000	F	MF	1.9	88
Rainbow trout	24-Apr-89	8,306	S	MF	5.8	88
Rainbow trout	25-Apr-89	1,344	S	MF	5.8	88
Rainbow trout	25-Apr-89	13,316	S	MF	4.6	88
Rainbow trout	30-May-89	9,705	S	MF	5.2	88
Rainbow trout	30-May-89	10,304	S	MF	5.2	88
Coho Salmon	31-May-89	58,659	F	MF	3.0	88

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Species	Stocking Date	Number Stocked	Age[a]	Sex[b]	Length (inches)	Brood Year
Rainbow trout	31-May-89	4,028	S	MF	5.2	88
Coho Salmon	2-Jun-89	53,176	F	MF	3.0	88
Coho Salmon	2-Jun-89	38,175	F	MF	3.0	88
Rainbow trout	7-Aug-89	150,000	F	MF	2.0	89
Rainbow trout	7-Jun-90	33,843	S	MF	5.0	89
Coho Salmon	16-Jul-90	52,000	F	MF	2.6	89
Coho Salmon	17-Jul-90	98,000	F	MF	2.6	89
Rainbow trout	19-Jul-90	150,632	F	MF	2.0	90
Rainbow trout	12-Sep-90	52,914	F	MF	2.5	90
Coho Salmon	16-Jul-90	52,000	F	MF	2.6	89
Rainbow trout	17-May-91	25,005	S	MF	4.9	90
Rainbow trout	17-Jun-91	17,711	S	MF	5.2	90
Coho Salmon	8-Jul-91	105,825	F	MF	1.9	90
Coho Salmon	11-Jul-91	45,960	F	MF	1.9	90
Arctic char	16-Jul-91	75,000	S	MF	4.0	90
Rainbow trout	31-Jul-91	152,000	F	MF	2.4	91
Rainbow trout	10-Jun-92	25,967	S	MF	5.5	91
Arctic char	19-Jun-92	30,000	F	MF	3.9	91
Rainbow trout	16-Jul-92	325,563	F	MF	2.2	92
Rainbow trout	22-Jul-92	75,046	F	MF	2.0	92
Coho Salmon	14-Jun-93	7,655	S	MF	4.0	91
Coho Salmon	24-Jun-93	160,600	F	MF	1.8	92
Rainbow trout	22-Jul-93	203,858	F	MF	2.1	93
Rainbow trout	27-Jul-93	217,043	F	MF	2.1	93
Chinook Salmon	6-Oct-93	12,568	C	MF	7.0	92
Coho Salmon	23-May-94	81,304	F	MF	3.0	93
Arctic char	21-Jun-94	20,000	F	MF	4.0	93
Arctic char	28-Jun-94	10,000	F	MF	3.7	93

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Species	Stocking Date	Number Stocked	Age[a]	Sex[b]	Length (inches)	Brood Year
Rainbow trout	11-Jul-94	179,406	F	MF	2.1	94
Coho Salmon	13-Jul-94	9,800	F	MF	3.3	93
Rainbow trout	13-Jul-94	201,000	F	MF	2.0	94
Coho Salmon	22-May-95	18,365	S	MF	5.1	93
Coho Salmon	23-May-95	11,337	S	MF	5.1	93
Coho Salmon	24-May-95	80,000	F	MF	3.1	94
Arctic char	14-Jun-95	28,904	F	MF	3.9	94
Coho Salmon	19-Jun-95	6,800	F	MF	2.2	94
Rainbow trout	17-Jul-95	78,261	F	MF	2.0	95
Rainbow trout	17-Jul-95	122,264	F	MF	1.9	95
Rainbow trout	20-Jul-95	97,425	F	MF	2.0	95
Rainbow trout	20-Jul-95	101,671	F	MF	2.0	95
Coho Salmon	29-May-96	80,000	F	MF	3.1	95
Rainbow trout	5-Aug-96	113,981	F	MF	2.3	96
Rainbow trout	5-Aug-96	109,181	F	MF	2.5	96
Rainbow trout	7-Aug-96	106,492	F	MF	2.5	96
Rainbow trout	7-Aug-96	20,706	F	MF	2.5	96
Rainbow trout	7-Aug-96	592	F	MF	2.5	96
Rainbow trout	7-Aug-96	30,208	F	MF	2.5	96
Rainbow trout	7-Aug-96	20,000	F	MF	2.5	96
Arctic char	4-Sep-96	30,000	F	MF	3.9	95
Arctic char	26-Sep-96	20,000	F	MF	4.4	95
Arctic char	2-Oct-96	5,338	F	MF	4.4	95
Coho Salmon	30-May-97	40,000	F	MF	2.9	96
Coho Salmon	31-May-97	40,000	F	MF	2.9	96
Rainbow trout	5-Jun-97	15,382	S	AF	6.6	96
Arctic char	6-Jun-97	30,000	F	MF	1.9	96
Rainbow trout	17-Jun-97	2,184	S	AF	6.6	96

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Species	Stocking Date	Number Stocked	Age[a]	Sex[b]	Length (inches)	Brood Year
Rainbow trout	11-Aug-97	49,935	F	MF	1.9	97
Rainbow trout	11-Aug-97	49,806	F	AF	2.3	97
Rainbow trout	11-Aug-97	110,931	F	MF	2.3	97
Rainbow trout	14-Aug-97	206,516	F	MF	2.3	97
Rainbow trout	10-Aug-98	193,825	F	MF	2.2	98
Rainbow trout	10-Sep-98	47,346	F	AF	2.4	98
Rainbow trout	10-Sep-98	34,535	F	MF	2.4	98
Rainbow trout	22-Sep-98	40,518	F	MF	2.8	98
Coho Salmon	7-Oct-98	41,209	F	MF	3.5	97
Coho Salmon	7-Oct-98	24,689	F	MF	3.6	97
Rainbow trout	7-Oct-98	12,276	F	AF	2.7	98
Coho Salmon	3-Jun-99	78,727	F	MF	2.9	98
Rainbow Trout	26-Jul-99	228	F	MF	2.1	99
Rainbow Trout	27-Jul-99	294,593	F	MF	2.1	99
Arctic Char	22-Aug-99	11,047	F	MF	3.9	98
Rainbow Trout	22-Aug-99	647	C	MF	6.3	98
Rainbow Trout	11-Oct-99	50,172	F	AF	3.1	99
Coho Salmon	12-Jun-00	84,321	F	MF	2.9	99
Coho Salmon	3-Aug-00	14,978	F	MF	3.7	99
Rainbow Trout	3-Aug-00	66,369	F	AF	1.8	0
Rainbow Trout	3-Aug-00	286,362	F	MF	2.1	0
Chinook Salmon	22-Sep-00	10,000	C	MF	7.6	99
Coho Salmon	11-Jun-01	58,000	F	MF	2.6	2000
Rainbow Trout	11-Jun-01	2,507	C	AF	8.6	2000
Rainbow Trout	11-Jun-01	2,500	C	MF	8.8	2000
Rainbow Trout	11-Jun-01	85	C	MF	12.3	2000
Rainbow Trout	28-Jun-01	2,745	C	MF	8.5	2000
Rainbow Trout	8-Aug-01	146,884	F	MF	1.8	2001

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Species	Stocking Date	Number Stocked	Age[a]	Sex[b]	Length (inches)	Brood Year
Rainbow Trout	8-Aug-01	78,705	F	MF	1.8	2001
Rainbow Trout	8-Aug-01	46,772	F	MF	1.9	2001
Arctic Char	31-Aug-01	9,065	S	MF	4.2	2000
Rainbow Trout	31-Aug-01	13,108	F	AF	2.5	2001
Rainbow Trout	31-Aug-01	27,775	F	MF	2.5	2001
Arctic Char	4-Sep-02	6,285	S	MF	3.6	2001
Rainbow Trout	3-Jun-02	6,682	C	AF	8	2001
Rainbow Trout	13-Jun-02	2,883	C	AF	7.8	2001
Rainbow Trout	27-Jun-02	7,005	C	AF	9.7	2001
Rainbow Trout[c]	Oct-02	99	C	MX	----	2001
Rainbow Trout	14-Aug-02	85,726	F	AF	1.9	2002
Rainbow Trout	14-Aug-02	167,767	F	AF	2	2002
Rainbow Trout	14-Aug-02	75,674	F	AF	1.9	2002
Rainbow Trout	4-Oct	7,242	S	MF	2.9	2002
Rainbow Trout	4-Oct	4,741	S	MF	3.2	2002

[a] E = eyed eggs, F = fingerling, S = subcatchable, C= catchable.

[b] MF = male and female diploid, AF = all female triploid.

[c] Rainbow trout catchables (n = 99) were transferred from Little Lost Lake to Quartz Lake during October, 2002.

APPENDIX F

Appendix F.-Method of Bernard and Clark (1996) to estimate contribution of catchable-sized fish stocked during 2001 as age-1 to the Quartz Lake population in 2002.

Contribution is estimated using:

$$\hat{r}_{ij} = \hat{N}_i\left(\frac{m_{ij}}{\lambda_i n_i}\right)\theta_j^{-1},$$

where: $\hat{r}_{ij}$ = the estimated number of fish from cohort *j* to population *i.*

m_{ij} = marks from cohort *j* recovered when sampling population *i,*

n_i = number of fish inspected for marks from population *i,*

λ = detection rate for marked fish (1 for this application),

$\hat{N}$ = estimated abundance of population *i,* and

θ_j = probability of fish from cohort *j* having a mark.

Sampling variance is estimated using:

$$V(\hat{r}_{ij}) = \hat{r}_{ij}^{\,2}[G(\hat{p}_{ij}) + G(\hat{N}_{ij}) - G(\hat{p}_{ij})G(\hat{p}_{ij})],$$

where:

$$G(\hat{p}_{ij}) = \frac{(1-\lambda_i\hat{\phi}_i\theta_j)}{m_{ij}},$$

$$\hat{\phi}_i = \frac{n_i}{\hat{N}_i}, \text{ and}$$

$$G(\hat{N}_i) = V(\hat{N}_i)\big/\hat{N}_i^2 .$$

-continued

Intermediate Values:

$G(\hat{p}_{ij}) = 0.120055$

$G(\hat{N}_{ij}) = 0.093823$

$\hat{\phi} = 0.06192$

Input Variables:

$m_{ij} = 8$

$n_i = 581$

$\hat{N}_i = 9383$

$V(\hat{N}_I) = 8260201$

$\lambda = 1$

$\theta_j = 0.63889$